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13. ABSTRACT (Maximum 200 words)

Two nonlinear sonar systems, TAMU NLS #1 and #2 have been designed and constructed. The first operates at a difference frequency of 24 kHz and uses a receiver that is a complete EDO Western 4034A sonar system in itself. With this nonlinear system one can probe a maximum distance of 257 feet (78 m) straight down in a salt mine.

System #2 has a difference frequency of 6 kHz, for the reason of obtaining more range in the rock than System #1. The lower primary frequencies will be less attenuated in beam forming at the difference frequency.

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ARO 21070.1-GS

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report

from the Texas A&M
RESEARCH FOUNDATION
College Station, Texas

FINAL REPORT

1. ARO PROPOSAL NUMBER: 2107-GS

2. PERIOD COVERED BY REPORT: 10 SEPT 1984- 9 MARCH 1990

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DEPARTMENT OF GEOPHYSICS

6. AUTHOR OF REPORT: DR. ROBERT R. UNTERBERGER
PROFESSOR OF GEOPHYSICS

MAY 9,1990

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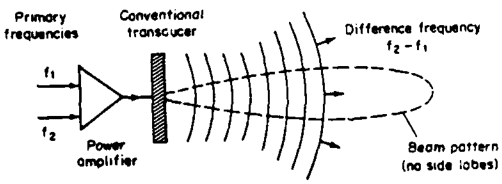
CHAPTER 1

INTRODUCTION

From our original interest in "seeing" or probing into rocks with radar, we were diverted to using sonar when certain rocks contained small amounts of water that attenuated the radar and made it impossible to get any decent range using radar. Sound waves worked fine, except that we kept needing a narrower beam of sonar investigation with the probing system. Larger transducers gave narrower beams, but kept getting bigger and heavier. Originally we thought that there was no way around this dilemma. Then we learned of nonlinear sound, (courtesy of Dr. Westervelt of Brown University) whereby,one can generate a narrow beam at a low frequency in rocks, using two high-powered, high-frequency beams that are colinear. With high power the rock is driven nonlinearly and the rock ITSELF generates the difference frequency. Furthermore, the beam has no sidelobes, unlike all other beams from normal acoustic transducers. The only disadvantage is the small power converted to delta f. The diagram below shows the basics of a nonlinear or paramteric sonar system. Unfortunately, there being no nonlinear sonar systems on the market, we had to build our own, and this is what we did.



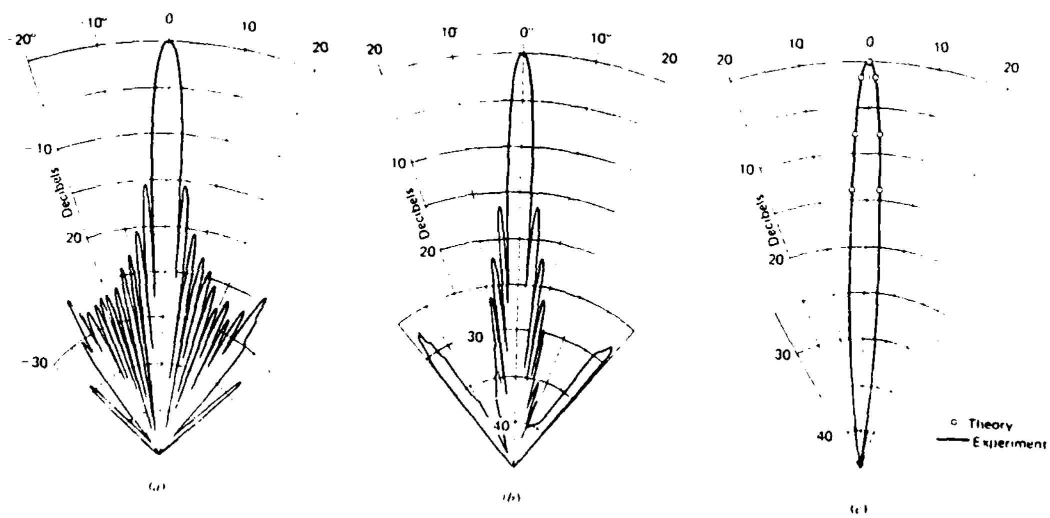
BASIC PARAMETRIC SONAR SYSTEM

Fortunately, as a test site for the equipment, we had access to a salt mine. We have been using the Morton Salt Company's Grand Saline salt mine for radar tests for some time. At the start of this project we could only make field tests of the NLS systems at the Grand Saline salt mine of Morton Salt Co. in their shop area. This was at the upper mining level and had half of the floor underlain by a tunnel in the salt. Thus, the northern half of the salt floor

could be used to test our sonar using the salt-air interface about 46 feet below. The shop was convenient, in that there was light, power, water, telephone, and shop tools available. What was inconvenient, was that the miners continuously used their air hose to clean themselves and their vehicles of salt dust, that quickly found its way into our electronic equipment. This was all right in this very dry mine, but when the equipment with salt reached normal weather (with moisture in the air), at TAMU, then corrosion started immediately. Also, since we were using coupling fluids such as castor oil, we did not feel this was the proper place for experiments. Being guests, we couldn't spill it on their floor.

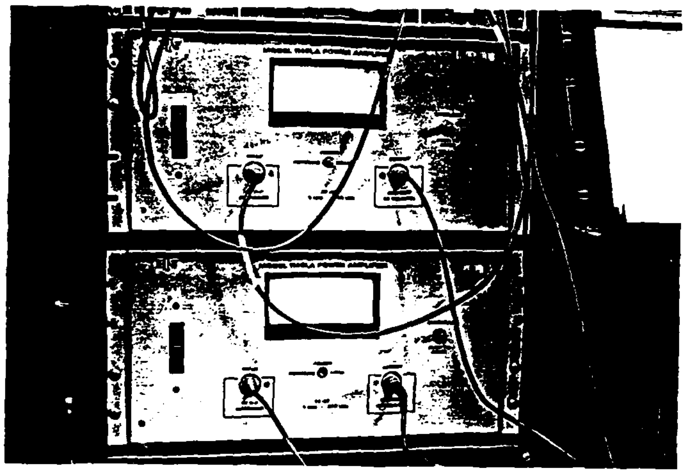
In looking around the mine, we found a good place about 200 yards away, that was convenient to work, with some known tunnels below the floor at 35 and 96 feet. We set up our equipment there, but there was no power, and Morton declined to run a power cable over. Thus, with permission of DOD we purchased our own 110 volt, 60 Hz generator to supply us with our own power. Actually, the machine is a Deutz (French) diesel-driven, Miller Starfire welding generator, that has 2-115 volt power outlets, and 3.5 kW power capacity to run all our electronic equipment.

A nonlinear or parametric beam is shown below, generated by water from two high intensity beams. Note the lower freqency beamwidth is almost equal to the high frequency beamwidth of the primaries, and the lack of side lobes of the water-generated difference-frequency beam.



Parametric transmitting array directivity patterns. (*a*) Beam pattern of 418 kHz primary. (*b*) Beam pattern of 482 kHz primary. (*c*) Difference frequency beam pattern. Theory, open points; experiment, solid lines. (Muir 1974).

A photograph of the two power amplifiers used to drive the nonlinear sonar primary transducers is shown below.



The remainder of this report covers the nonlinear sonar systems designed and built, their tests at Lake Travis, the salt mine tests, and some information on the data reduction that we worked out using a computer. The last is given in Appendix A and B. A partial nonlinear sonar bibliography is given in Appendix C.

CHAPTER 2

NONLINEAR SONAR SYSTEM DESCRIPTION

We have developed two systems, TAMU NLS #1 and #2. The first operates at primary frequencies of 90 and 114 kHz. At the difference frequency of 24 kHz, we use an EDO Western sonar as a receiver. A block diagram is shown in Figure 1. The second system was built to operate at a much lower frequency in order to get more sonar probing range in rocks. Thus the primaries were designed to be 36 and 42 KHz respectively. This is shown in block diagram form in Figure 2. As a receiver for the difference frequency of 6 kHz, we chose the F-50 hydrophone shown in Figure 3. Figure 4 shows it has omnidirectional characteristics at this low frequency. The System #1 transducer has a diameter of 17 inches with a cone throat of 15 inches in diameter. It is shown in Figure 5. That of System # 2 is shown in Figure 6. It has a 36 inch diameter and a cone throat of 34 inches. Both of these units were built to our specifications by the International Transducer Corp. of California.

NLS Receiver Configurations

Many receiver configurations were tried during this research in an effort to find the best system, i.e. those giving the maximum signal to noise ratio for the received signal. These are listed below.

System A

	T-R box or 24 kHz transducer	to
	Trodyne preamplifier (gain= 50)	to
	Krohn-Hite filter	to
	Hewlett Packard 466A amplifier	to
	Tektronix 465 oscilloscope	

System B

	T-R Box or 24 kHz transducer	to
	Preamplifier	to
	K-H filter	to
	466A amplifier	to
	K-H filter	to
	Diode detector	to
	Oscilloscope	

System C

	T-R Box or 24 kHz transducer	to
	466A amplifier	to

JHM 01A amplifier,20,40,60 dB to
Tektronix AF 501 band-pass amplifier to
Diode detector to
Oscilloscope

System D

F-50 hydrophone to
Butterworth 10 kHz filter to
Trodyne amplifier to
K-H filter to
Oscilloscope

System E

F-50 hydrophone to
Butterworth 10 kHz filter to
Geopulse receiver to
Oscilloscope

Hydrophone and Butterworth Filter

The F-50 hydrophone was chosen to detect the 6 kHz nonlinear signal in salt, because of its small size, its receiving sensitivity patterns, and because it had no built-in preamplifier. Any amplifier would be driven nonlinearly by the high intensity (primary) sound beams used in this research. The unit was rented from the U.S. Navy in Florida and was returned after contract completion. We always fed the hydrophone output into a Butterworth filter. The characteristic loss at the primary frequencies for the 10 kHz Butterworth filter was 75 dB down at 36 kHz and 79 dB down at 42 kHz. It was made for us by S.S. White of Austin, Texas.

The next chapter describes the basic tests we carried out on the transducers and the systems, at the University of Texas, Applied Research Laboratory's separate facility known as the Lake Travis Test Station.

TAMU NONLINEAR SONAR SYSTEM
BLOCK DIAGRAM

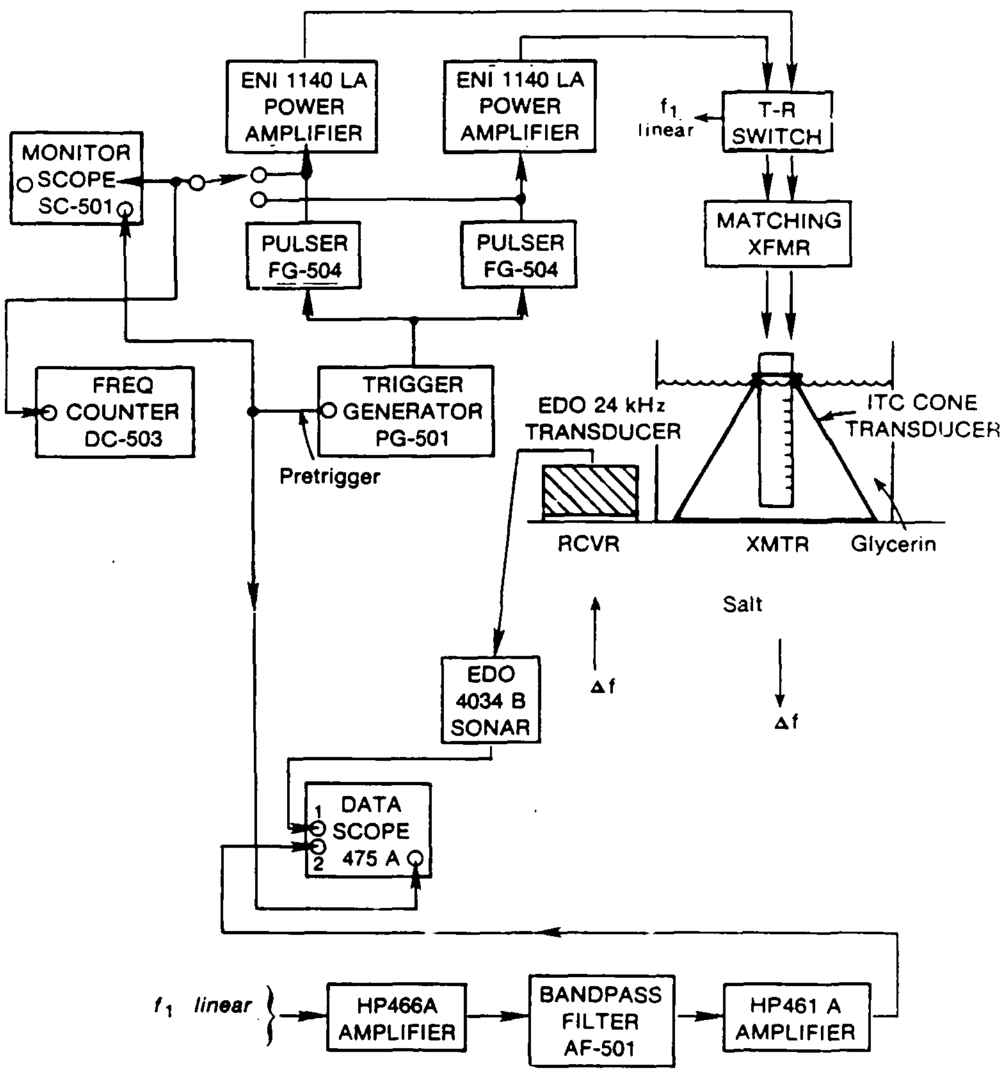


Figure 1. Block Diagram of TAMU Nonlinear Sonar System

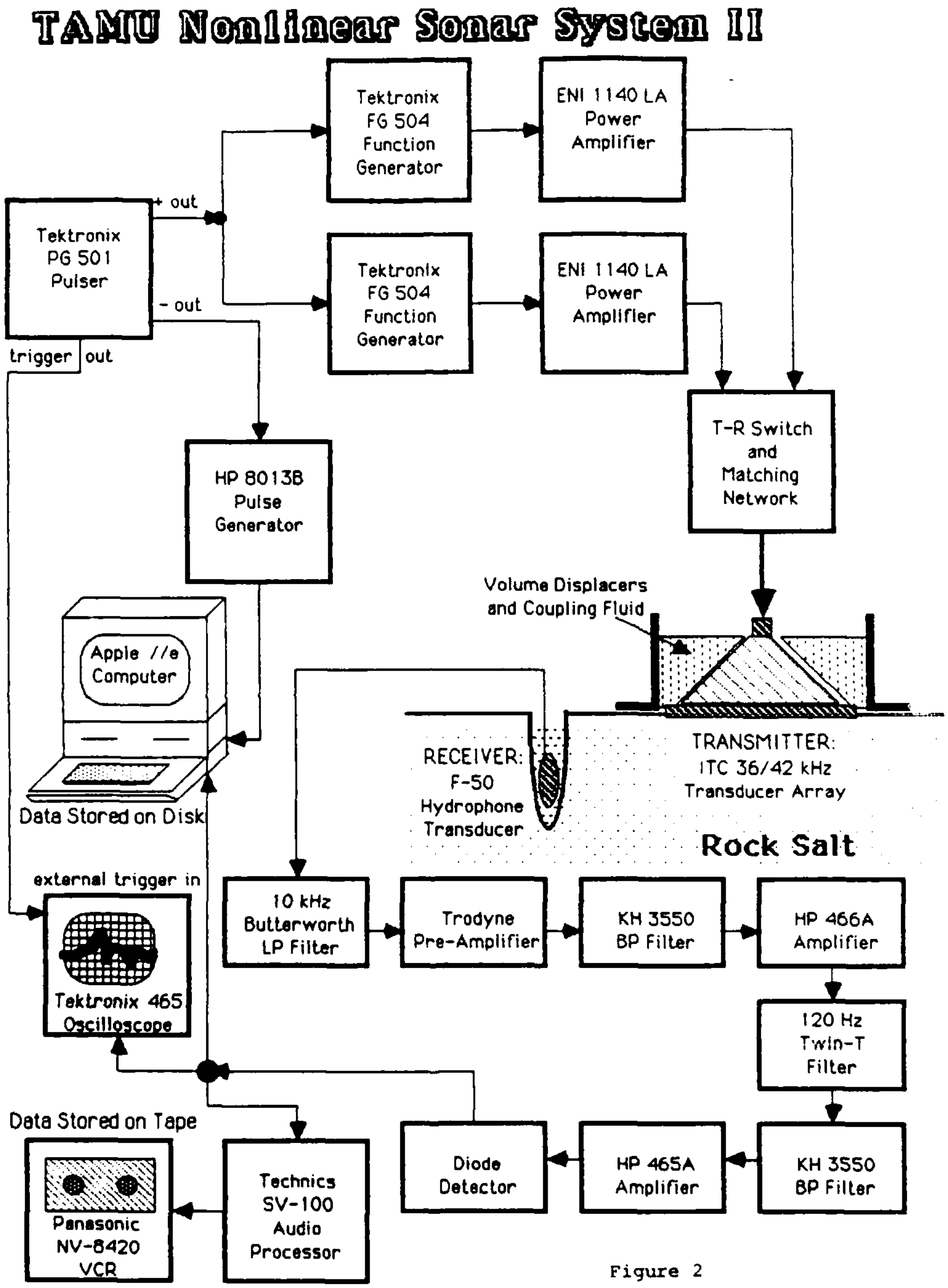


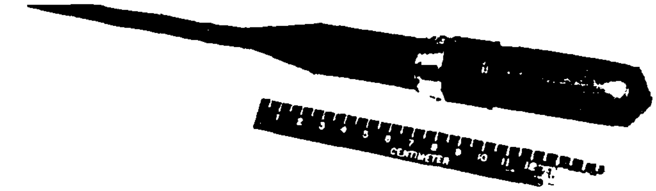
Figure 2

TAMU Nonlinear Sonar System
#2 Block Diagram

TYPE F50 TRANSDUCER

General Description

The USRD Type F50 Transducer was designed for use primarily as an underwater sound receiver in the frequency range 1 Hz to 70 kHz; however, it can be used as a sound source in the frequency range 10 to 70 kHz. The active sensor element consists of lead zirconate-titanate cylinders mounted coaxially and mechanically isolated from each other in an oil-filled, butyl boot. Normally, these transducers are supplied with a 23-m 2-conductor shielded cable. Figure 71 is a photograph of the transducer.



15"

Fig. 71. USRD Type F50 Transducer.

Specifications

Frequency range:	1 Hz to 70 kHz
Free-field voltage sensitivity (nominal):	-205 dB re 1 V/μPa at end of 23-m cable, below 10 kHz
Transmitting voltage response:	117.5 dB re 1 μPa/V at 20 kHz
Maximum driving voltage:	200 V rms (300 V pulse, 30% duty cycle)
Nominal capacitance:	0.015 μF at end of 23-m cable
DC resistance:	greater than 1000 MΩ
Maximum hydrostatic pressure:	6.9 MPa (690-m depth)
Operating temperature range:	0 to 35°C
Weight with 23-m cable:	4.3 kg
Shipping weight:	8.6 kg

Electroacoustic Characteristics

The free-field voltage sensitivity of the Type F50 Transducer is determined by comparison with standard hydrophones in free-field measurements, or by the reciprocity method. Figure 72 shows a typical free-field voltage sensitivity curve in terms of open-circuit voltage at the end of a 23-m cable. A calibration curve is provided with each transducer.

Figure 3

F-50 Hydrophone

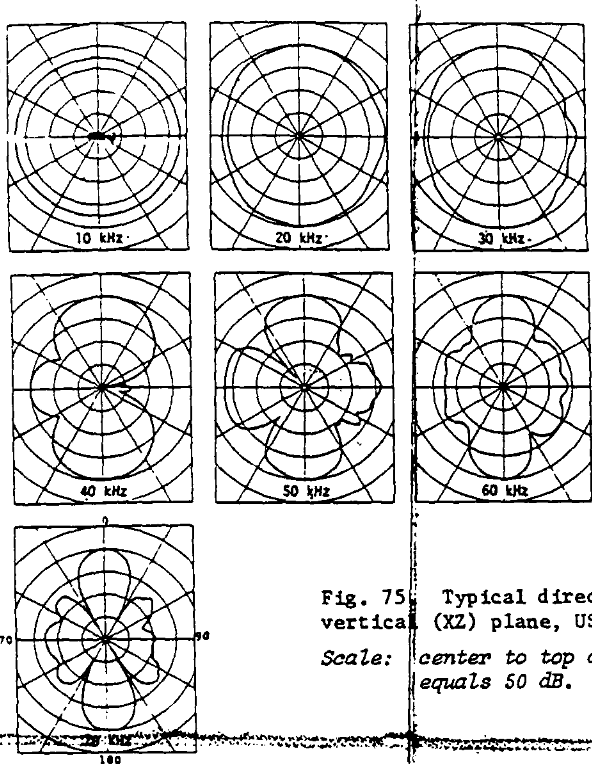


Fig. 75. Typical directivity patterns in the vertical (XZ) plane, USRD Type F50 Transducer.
Scale: center to top of grid, each pattern, equals 50 dB.

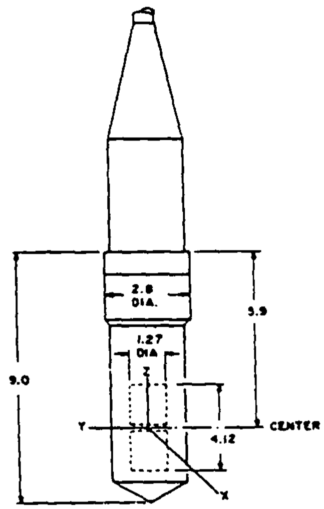


Fig. 76. (Right) Dimensions (in centimeters) and orientation of Type F50 Transducer.

Figure 4

F-50 Hydrophone directivity

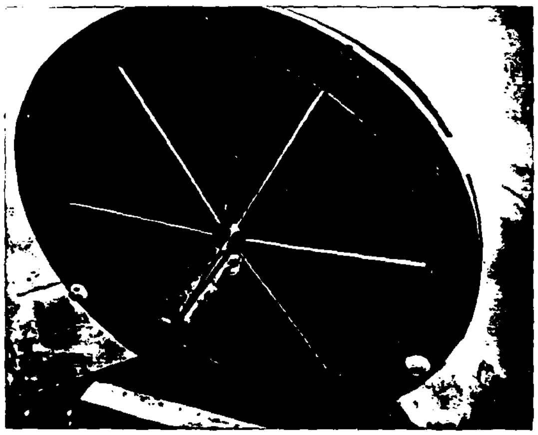


Figure 5

Transducer of TAMU NLS #1

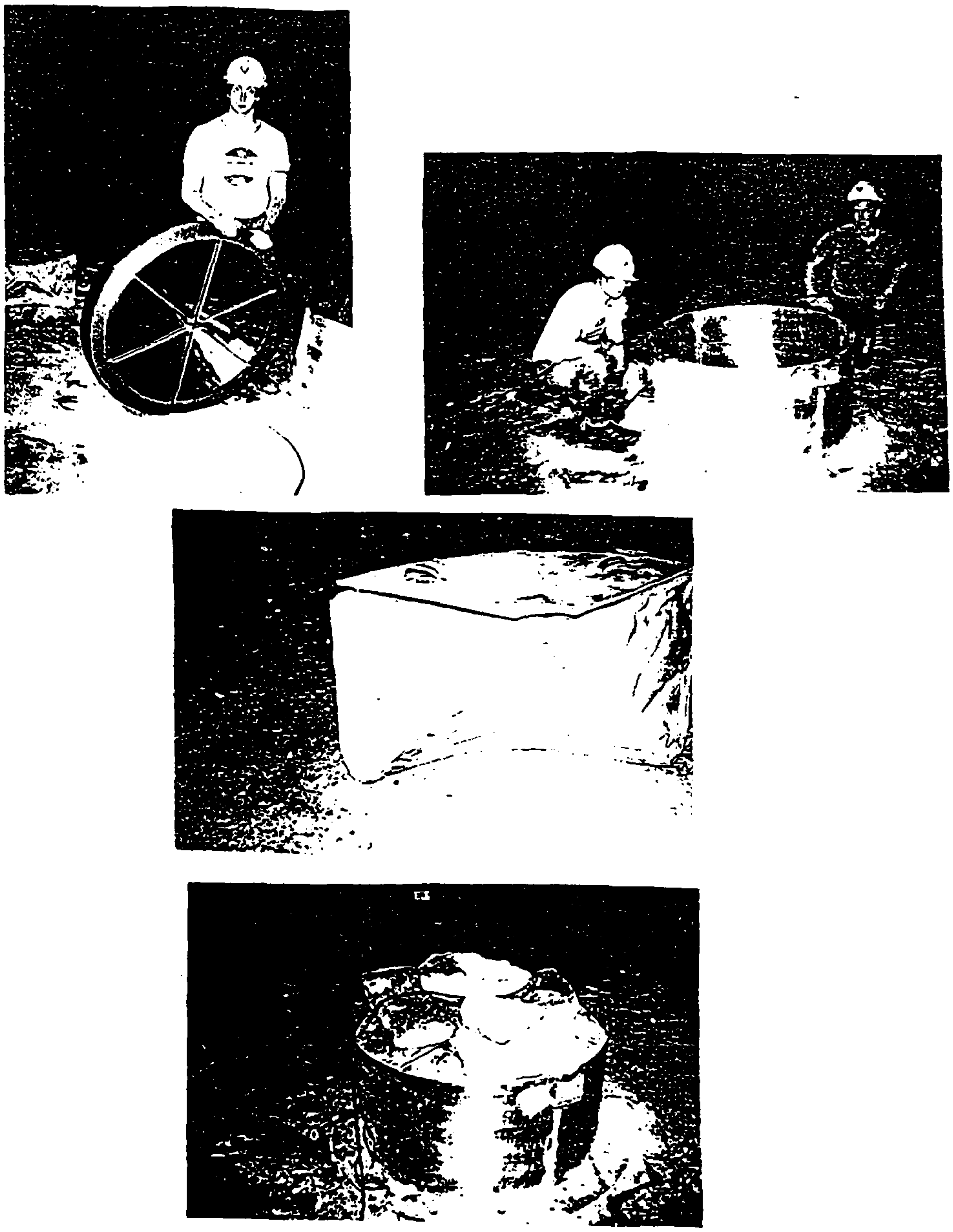


Figure 6

Transducer of TAMU NLS #2

CHAPTER 3

SONAR TRANSDUCER TESTS AT LAKE TRAVIS TEST STATION

Using the Lake Travis Test Station facilities of the Applied Research Laboratory of the University of Texas at at Austin, (Dr. Thomas Muir's home base), we were able to test each of the two nonlinear systems and their transducers in water. We measured the individual linear beamwidth of the two primaries in each of the systems as well as measuring the nonlinear difference-frequency beamwidths in the water. Figure 7 shows the beamwidth of the transducer operating at 90 kHz in a linear mode. Figure 8 shows a more detailed beamwidth plot, from which we get the angle between the half power (3 dB down) points to be 2.5 degrees. Figure 9 shows a similar plot for the 114 kHz transducer. The difference frequency of 24 kHz has a beamwidth of only 3.4 degrees as shown in Figure 10 and, in more detail, Figure 11. This is rather remarkable as the transducer is only 14 inches at the cone throat, and weighs only 15 pounds. A linear transducer at the same frequency, namely our 6122 EDO transducer, weighs 35 pounds and is 9 inches in diameter, and has a beamwidth in water of 20 degrees! This is shown in Figure 12. This is one big advantage of the NLS system. Another is that the difference-frequency beam has no sidelobes. The sharp narrow peaks you see on Figure 10 are coming from outside sources of noise in the lake, such as dam operations, motorboats, water skiers, fish, etc. Figure 13 shows a photograph of the received 24 kHz generated by the water of Lake Travis. It is 0.3 ms long; the sweep is 50 us/div.

For similar results for the lower frequency transducer of TAMU NLS #2, see Figure 14 and Figure 15. Here the beamwidth of the 36 kHz transducer is 2.7 degrees. The beamwidth of the 42 kHz transducer,see Figure 16 and Figure 17, is 2.4 degrees, slightly less due to the higher frequency of operation. Again, with slightly different primary frequencies, we see that Figures 18 and 18A show the beamwidth of the difference frequency of 4.1 kHz to be 3 degrees in water. Figure 19 shows the actual 2 ms pulse in the water as observed on the oscilloscope screen. The nonlinear pulse does the three things it is supposed to do:

1. Reduce to zero when the primary frequency f one is turned off, but f two is at full power.

2. Reduce to zero when the primary frequency f two is turned off, but f one is at full power.

3. Change frequency as either primary is changed, and is always equal to the difference frequency of the two primaries.

Figure 20 shows tha measured beamwidth when the actual difference frequency is 6 kHz.

Sound Pressure Measurements at 36 and 42 kHz

Using a current transformer in the line feeding the transducer, we measured the current into the transducer at 36 kHz as 4.95 amperes, or a power of 1224 watts, with 2.2 volts p/p feeding the transducer from the ENI amplifier input. The actual SPL (sound power level) is obtained from the output voltage measurements of the hydrophone, the hydrophone calibration curve, the sensitivity of the hydrophone at a particular frequency, and a correction for spreading loss. Thus, we found that:

At 36 kHz -- SPL = 226.2 dB re 1 uPa @ 1 m., and

At 42 kHz -- SPL = 230.2 dB re 1 uPa @ 1 m.

APPLIED RESEARCH LABORATORIES
DIRECTIVITY PATTERN
TRANSDUCER No. ______

FREQ 90 kHz lin

R ______ m

PATTERN MODE

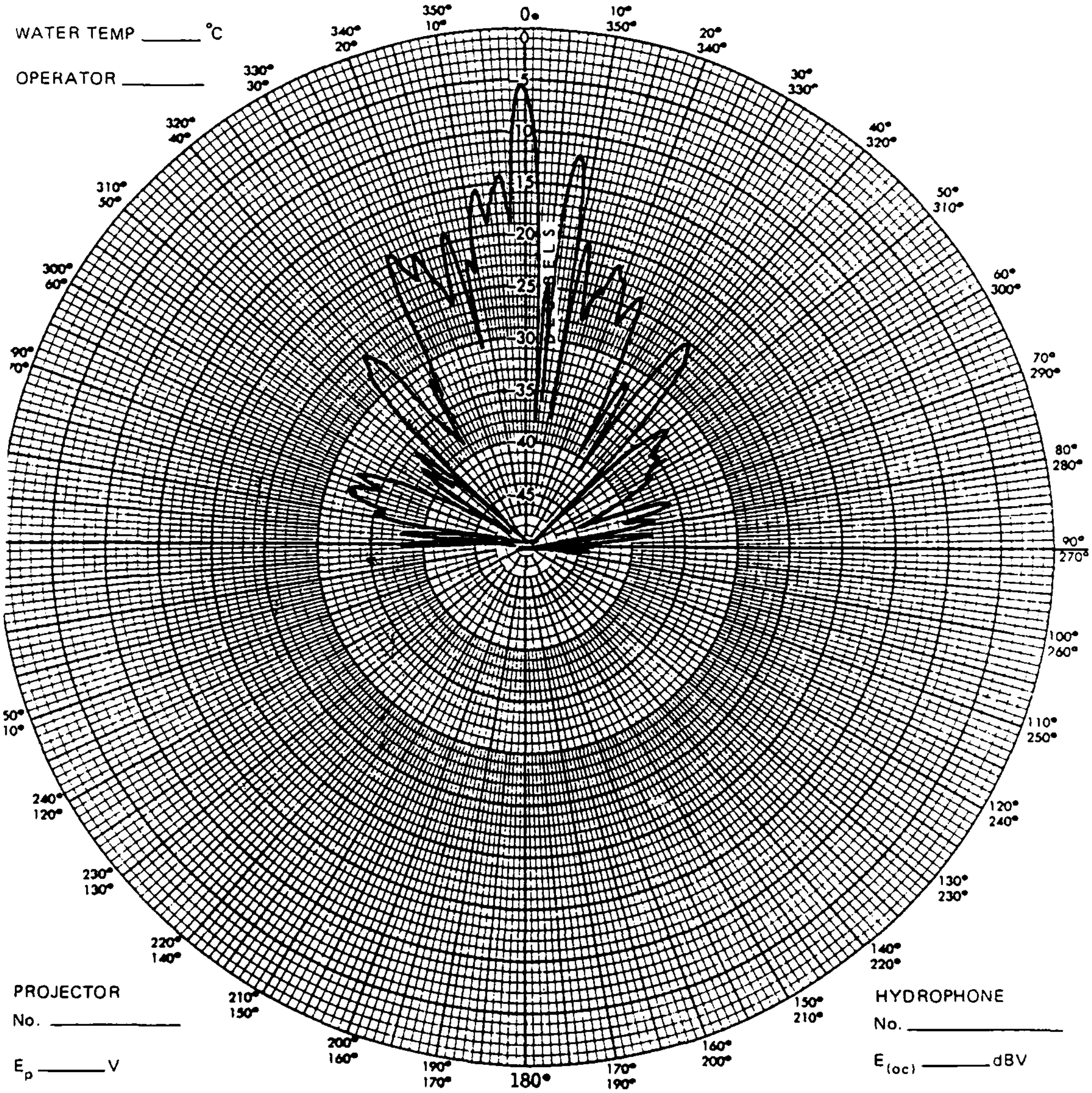
DATE 26 Ap

REC ___ PROJ ___ VERT ___ HORIZ ___

d ______ m

WATER TEMP ______ °C

OPERATOR ______



PROJECTOR
No. ______

E_p ______ V

I_p ______ mA

HYDROPHONE
No. ______

$E_{(oc)}$ ______ dBV

REC SENS ______ dB re / V/μ Pa

TVR ______ dB re / μ Pa/ V

FILTERS SET ______

Figure 7

Beamwidth of 90 kHz transducer operating linearly

PRF ______ H

______ ms

NOTES

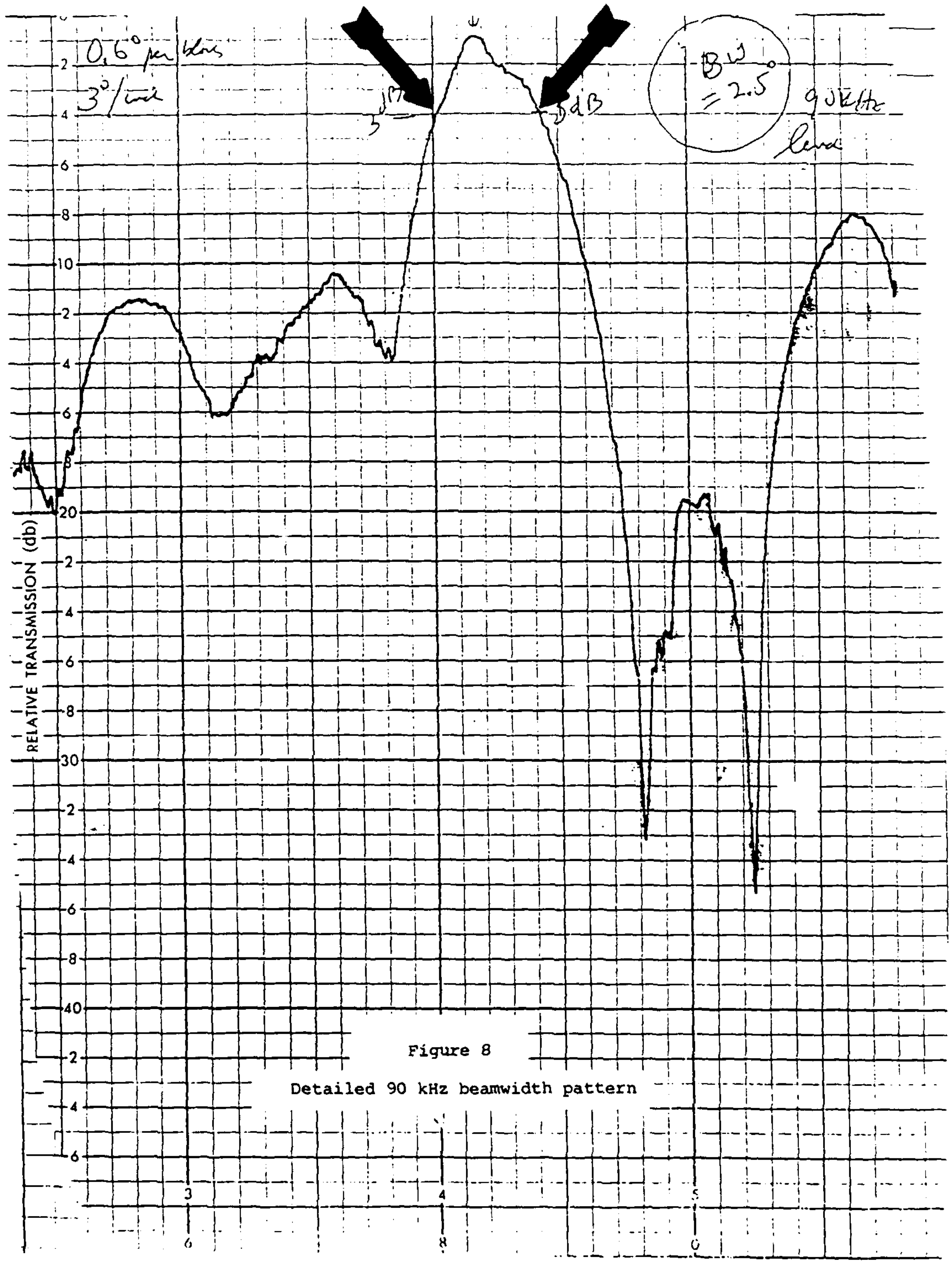


Figure 8

Detailed 90 kHz beamwidth pattern

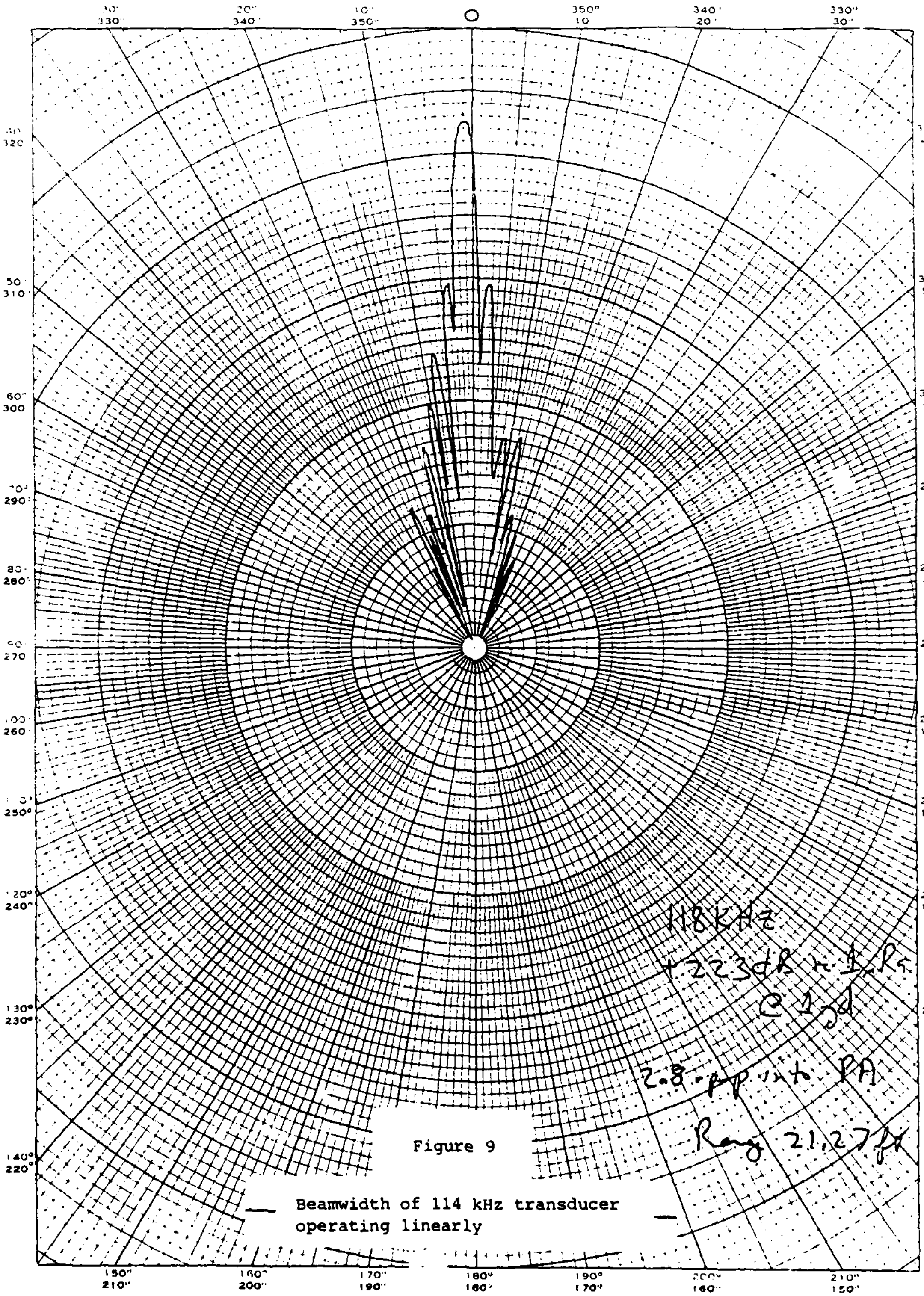


Figure 9

Beamwidth of 114 kHz transducer operating linearly

APPLIED RESEARCH LABORATORIES
DIRECTIVITY PATTERN
TRANSDUCER No. ______

D
FREQ 24 kHz

R 58 ft

d 11 ft

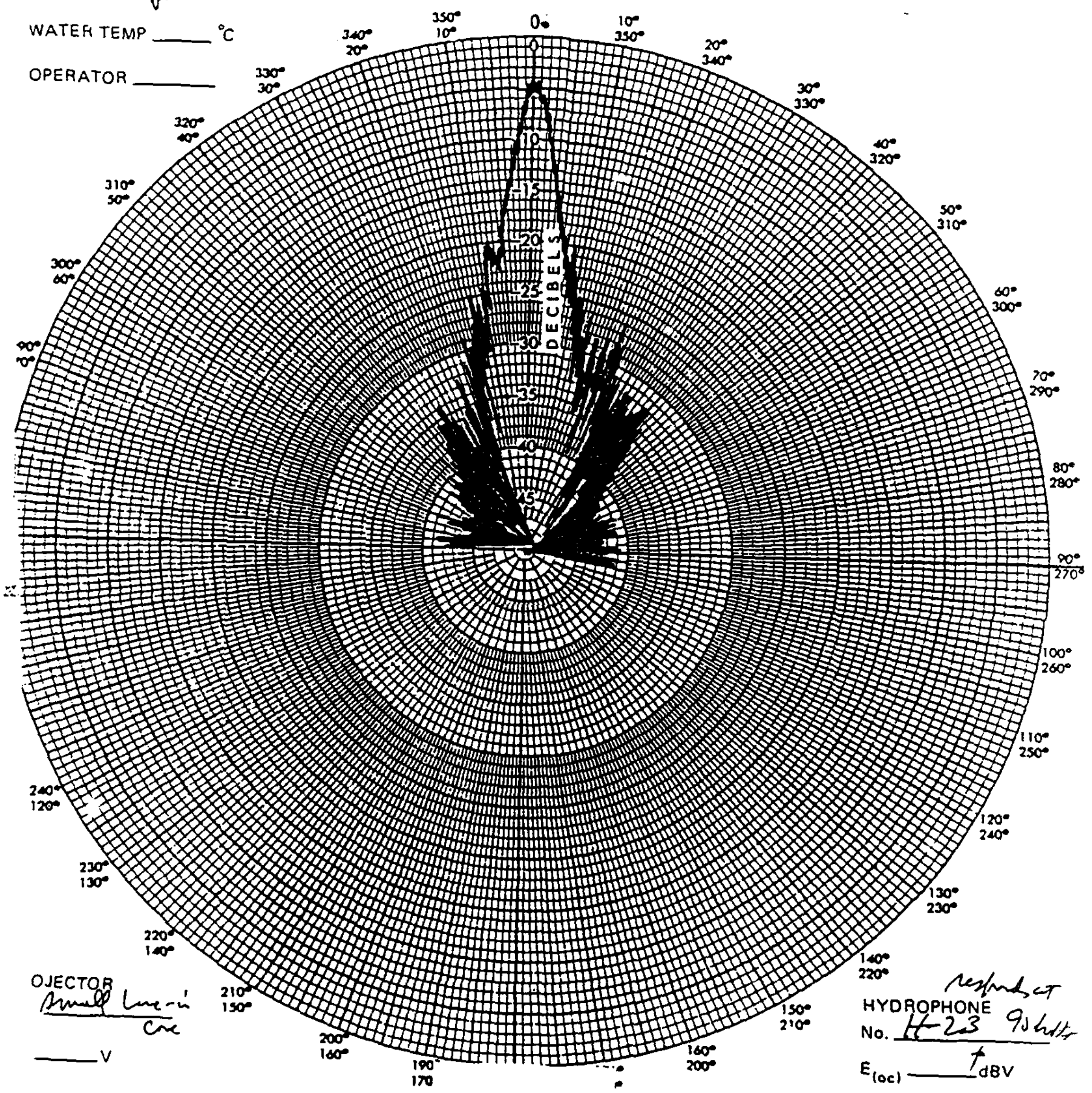
WATER TEMP ______ °C

OPERATOR ______

PATTERN MODE

REC ___ PROJ ___ VERT ___ HORIZ ___

DATE ______



OJECTOR
Small Line-in Cre

______ V

______ mA

HYDROPHONE
No. H-23

$E_{(oc)}$ ______ dBV

REC SENS ______ dB re / V/μ Pa

______ dB re / μ Pa/ V

Figure 10

FILTERS SET ___

PRF ______ Hz, X.

Difference-frequency beamwidth at 24 kHz

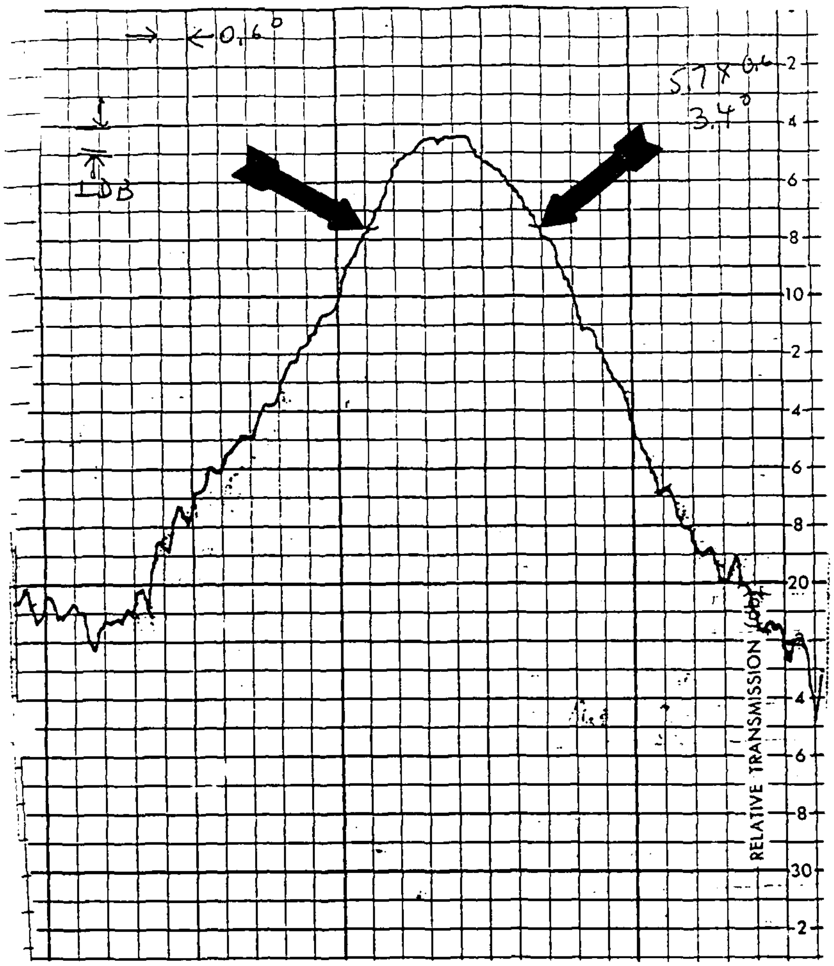


Figure 11

Plot of beamwidth at 24 kHz
difference-frequency

Bw = ±10° water

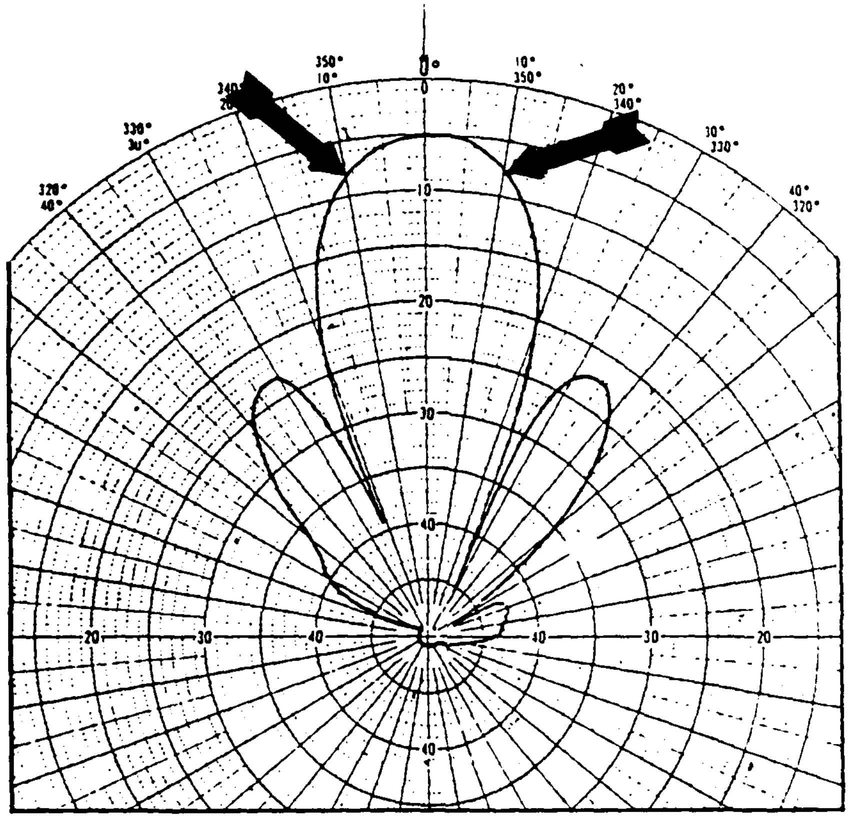


Figure 4   Radiation pattern of sonar transducer in water in a plane perpendicular to the plane of the transducer. The radial scale of the diagram is in dB; the azimuthal scale is in degrees. Zero degrees corresponds to the axis of transducer orientation. The radiation pattern was obtained from the Edo Western Corporation, the manufacturer of the sonar transducer.

Figure 12

EDO Western 24kHz Transduces beamwidth

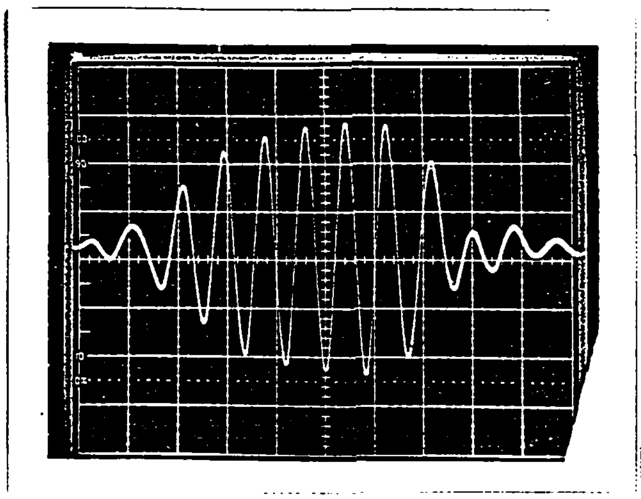


Figure 13

Photograph of 24 kHz signal
in water. Sweep=50 us/div.

APPLIED RESEARCH LABORATORIES
DIRECTIVITY PATTERN
TRANSDUCER No. ______

FREQ 36 kHz

DATE 26 Apr

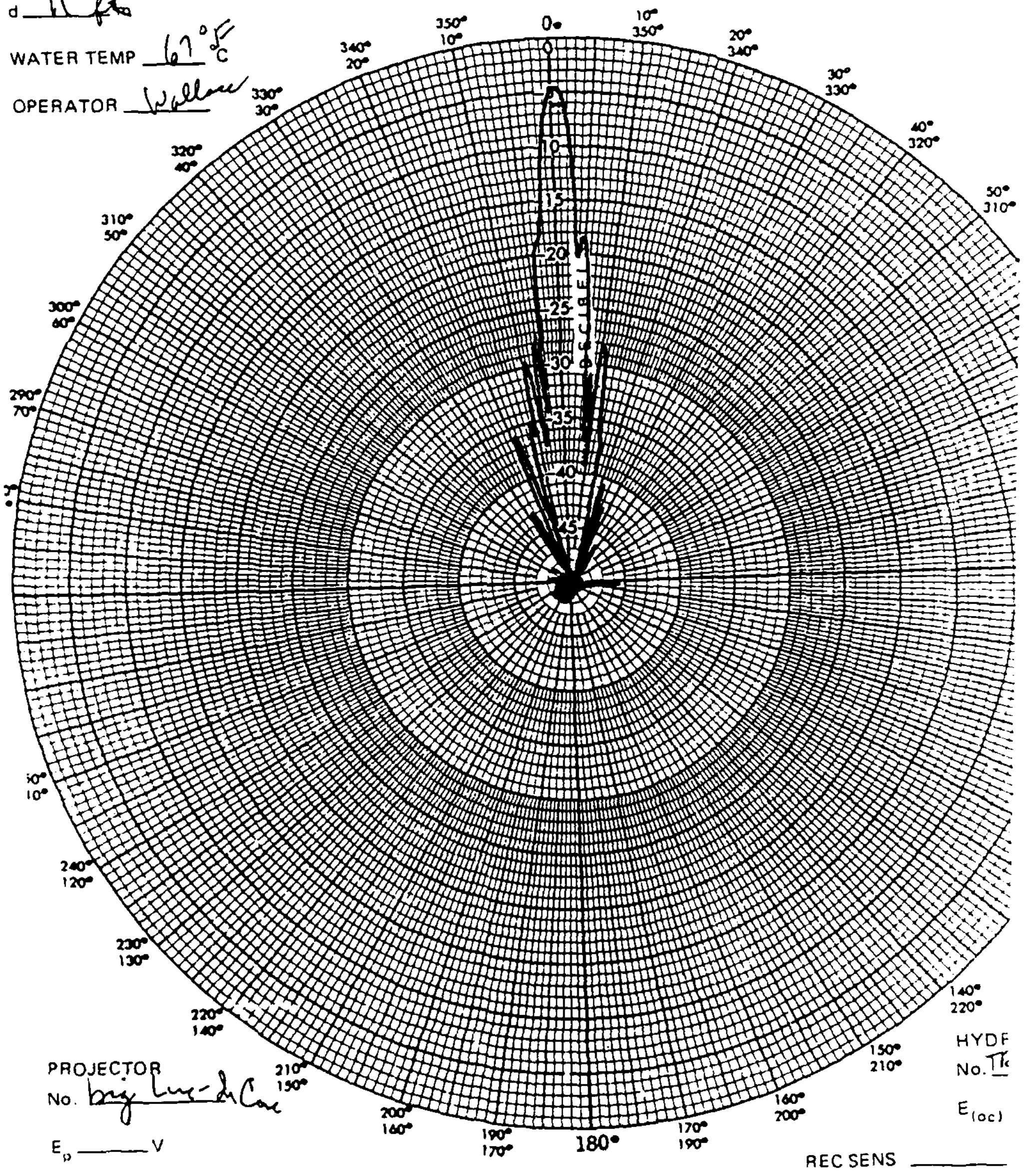
PATTERN MODE
REC ___ PROJ ___ VERT ___ HORIZ ___

R ______ m

d 11 ft

WATER TEMP 67°F C

OPERATOR Wallace



PROJECTOR
No. big Lux-deCoc

HYDF
No. Tk

$E_{(oc)}$

E_p ______ V

I_p ______ mA

REC SENS ______

TVR ______

FILTERS SET ______

PRF ______

'NGTH ______ ms

NOTES ______

Figure 14

Beamwidth of 36 kHz transducer operating linearly

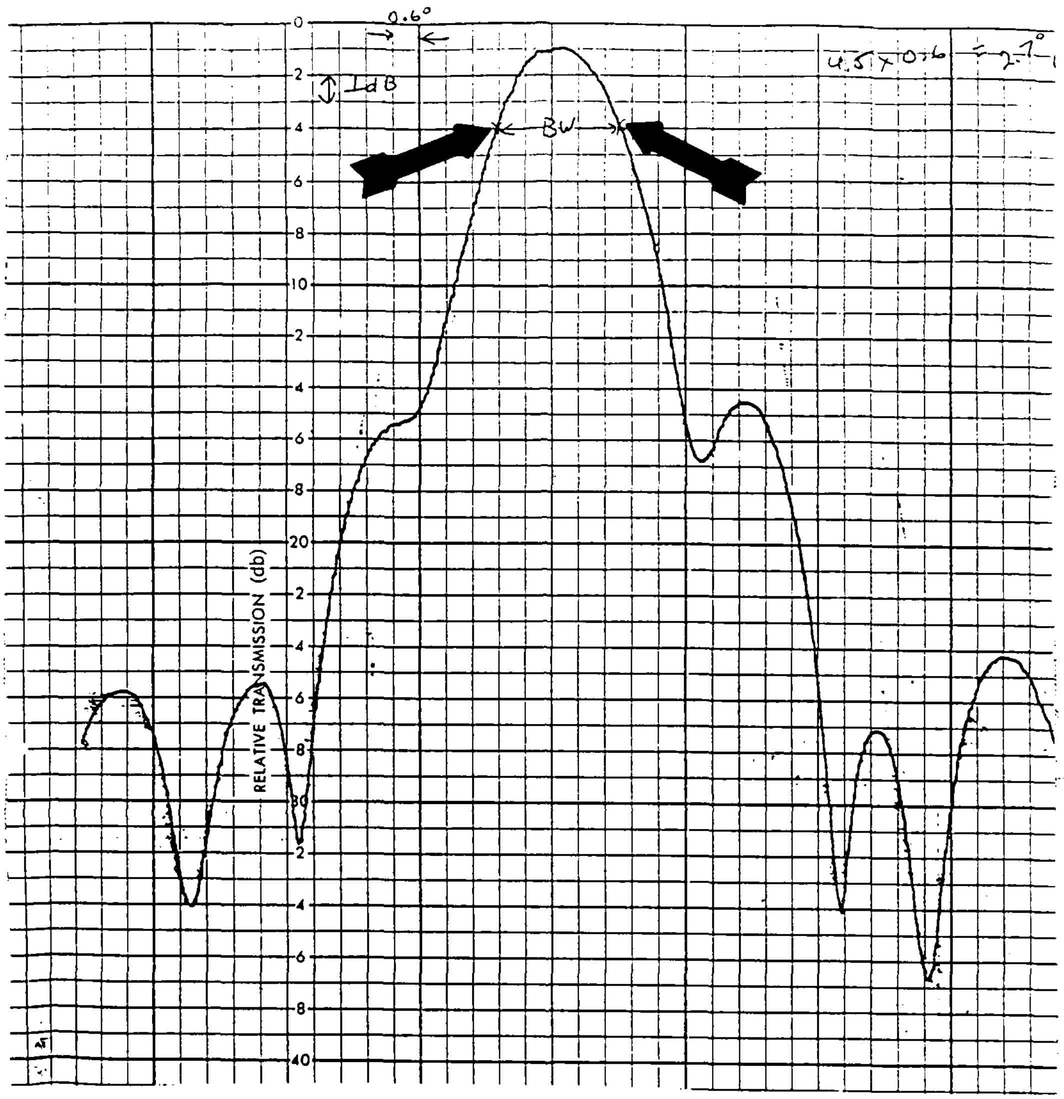


Figure 15

Detailed beamsidth at 36 kHz

APPLIED RESEARCH LABORATORIES
DIRECTIVITY PATTERN
TRANSDUCER No. ______

FREQ 42 kHz

R 48 m ft

d ___ ft

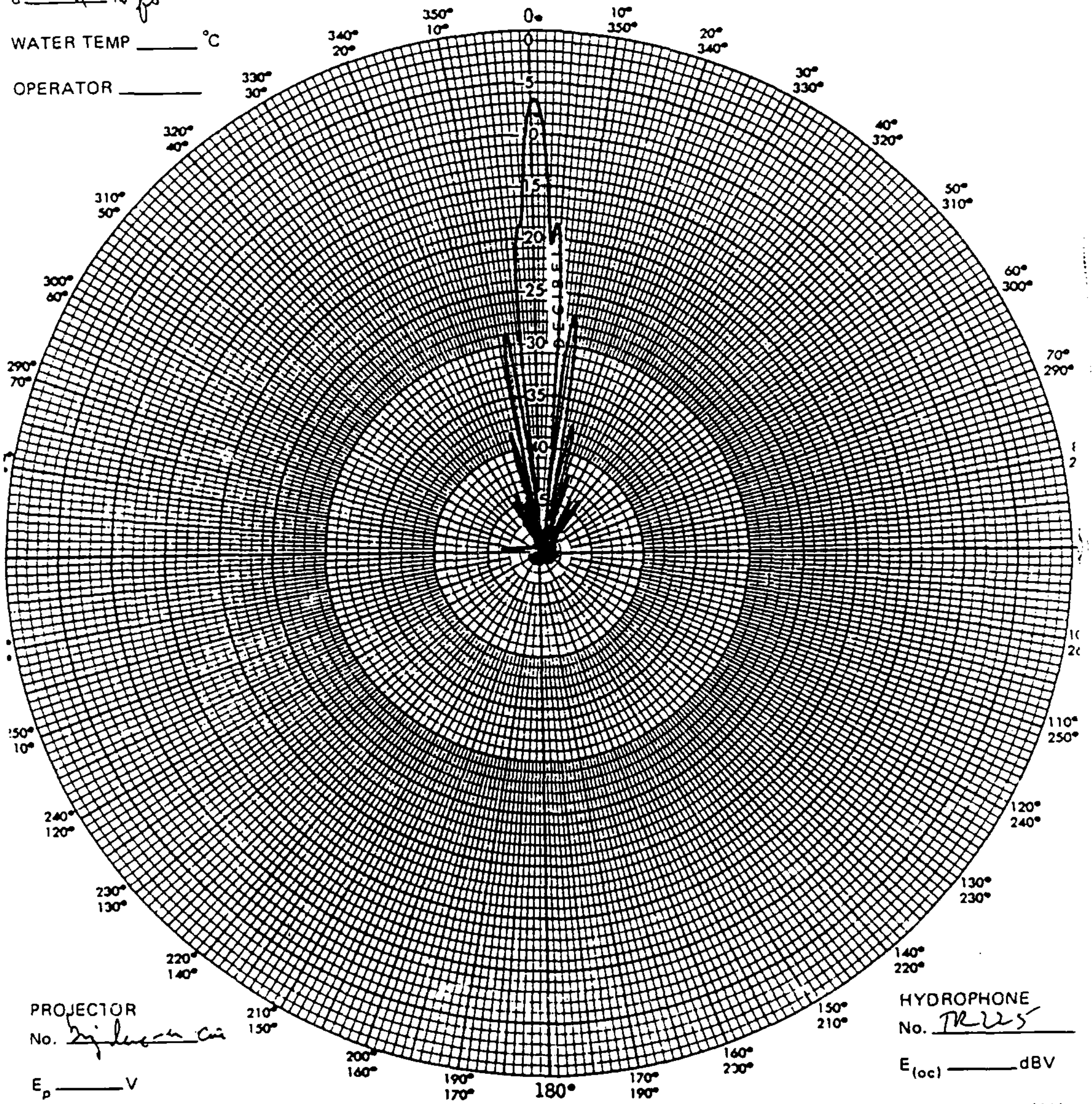
WATER TEMP ____ °C

OPERATOR ______

PATTERN MODE

REC ___ PROJ ___ VERT ___ HORIZ ___

DATE Apr 26 88



PROJECTOR
No. [illegible]

E_p ____ V

I_p ____ mA

FILTERS SET

HYDROPHONE
No. TR225

$E_{(oc)}$ ____ dBV

REC SENS ______ dB re / V/μ

TVR ______ dB re / μ Pa

Figure 16

Beamwidth of 42 kHz transducer
operating linearly

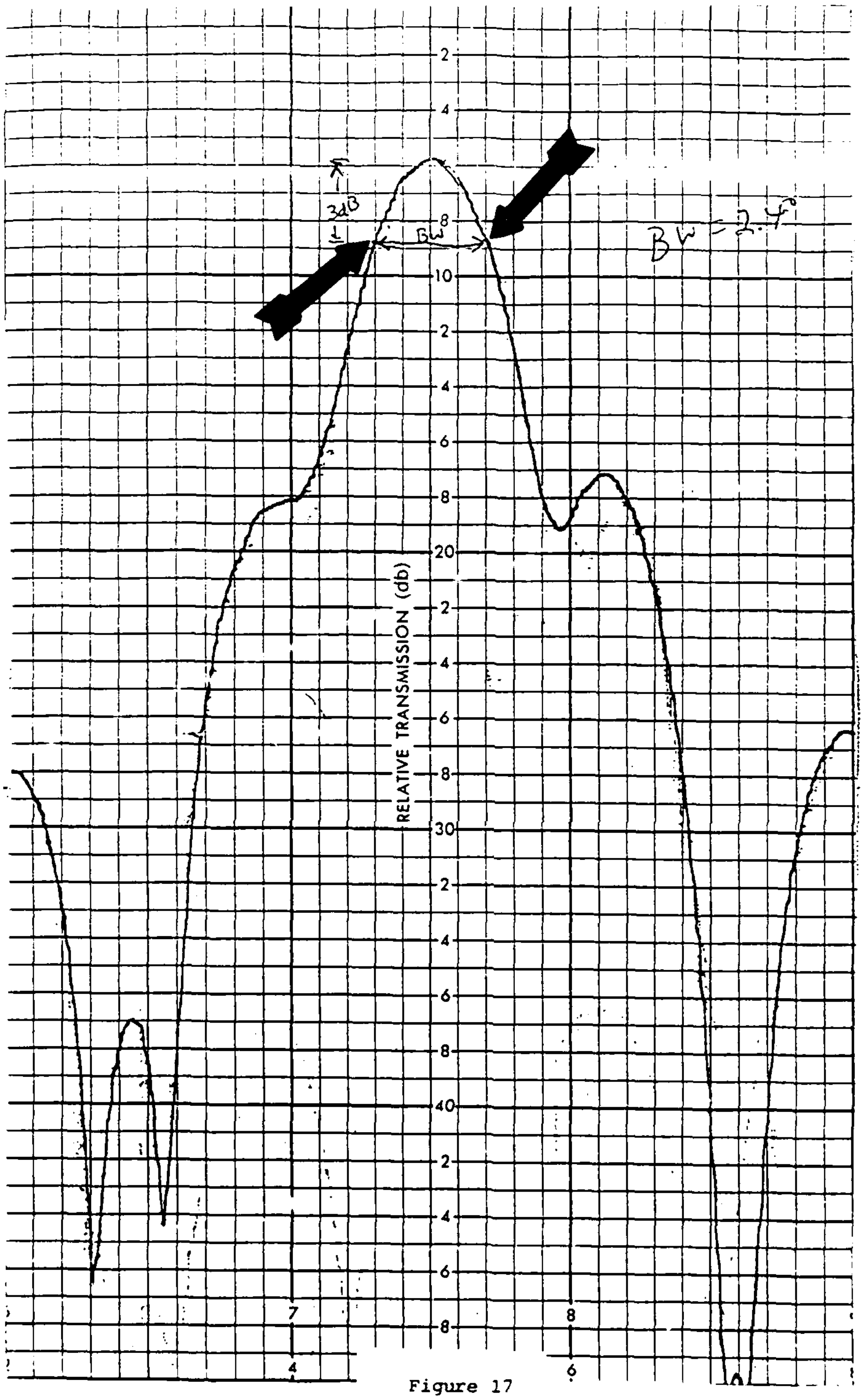


Figure 17

More detailed beamwidth at 42 kHz

APPLIED RESEARCH LABORATORIES
DIRECTIVITY PATTERN
TRANSDUCER No. ______

FREQ Δf=4.1 kHz kHz

R ______ m

d ______ m

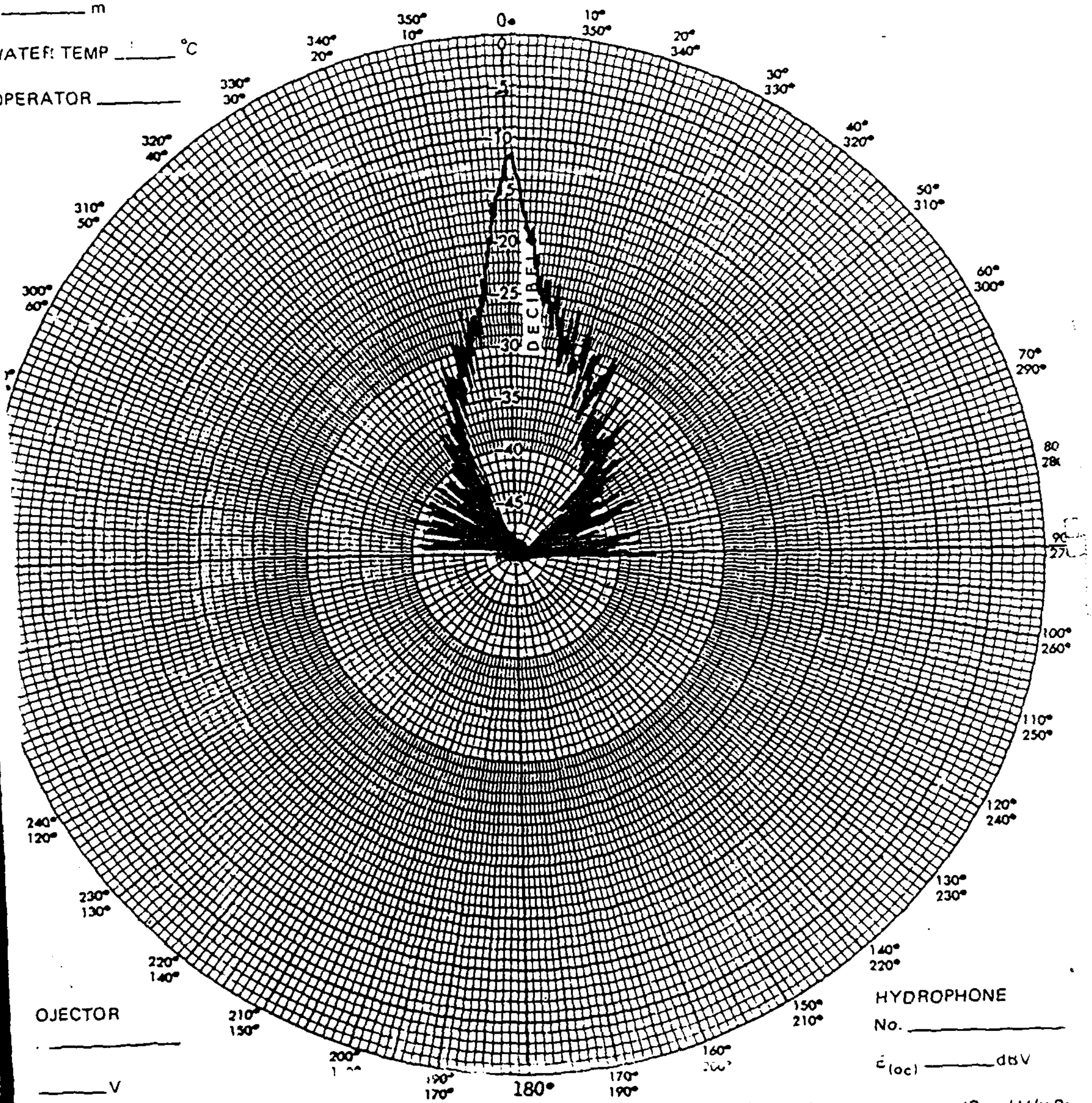
WATER TEMP ______ °C

OPERATOR ______

DATE Apr 84

PATTERN MODE

REC ___ PROJ ___ VERT ___ HORIZ ___



OJECTOR

______

______ V

______ mA

FILTERS SET ______

HYDROPHONE
No. ______

$e_{(oc)}$ ______ dBV

REC SENS ______ dB re / V/μ Pa

TVR ______ dB re / μ Pa/ V

Figure 18

Difference-frequency beamwidth at 4.1 kHz

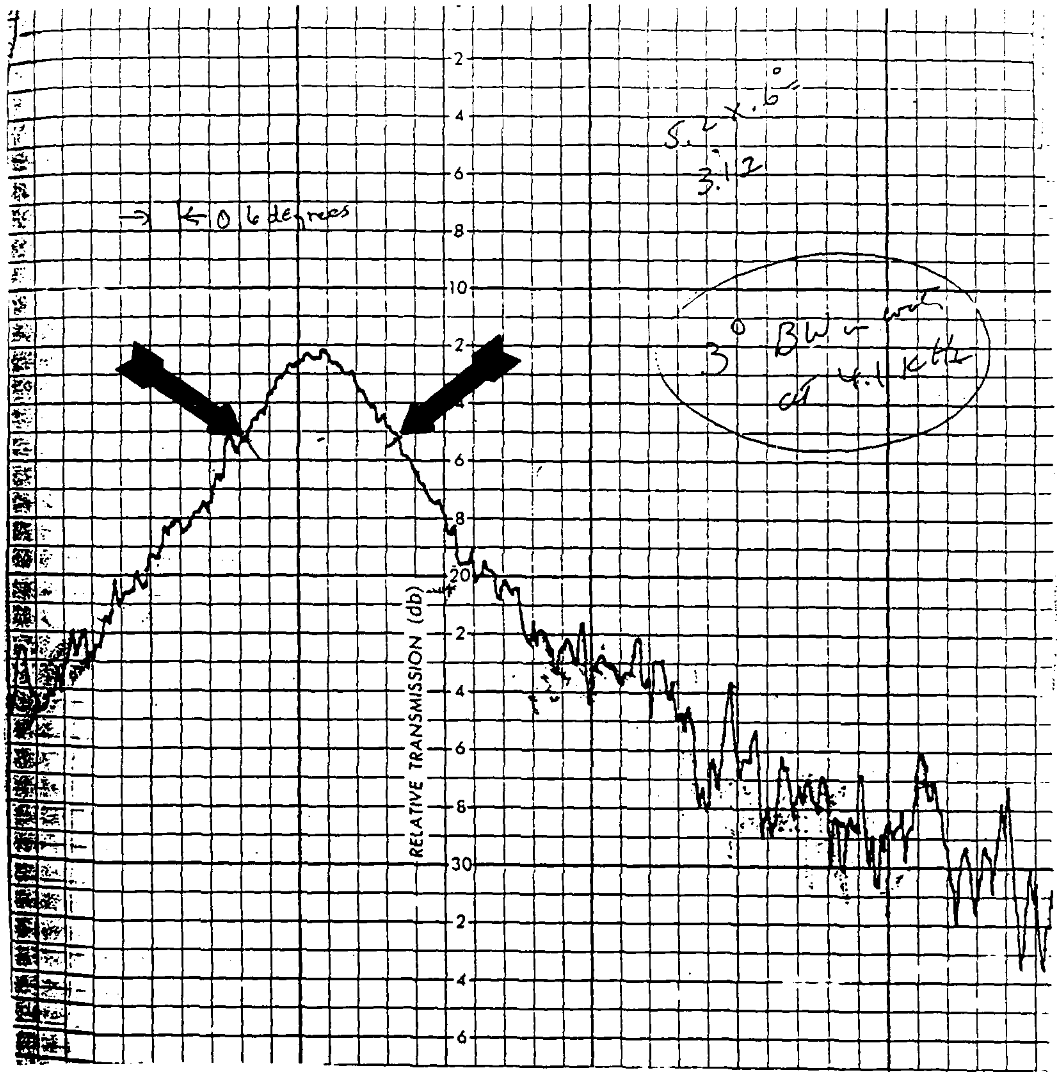


Figure 18A

More detailed beamwidth at
4.1 kHz=3.1 degrees

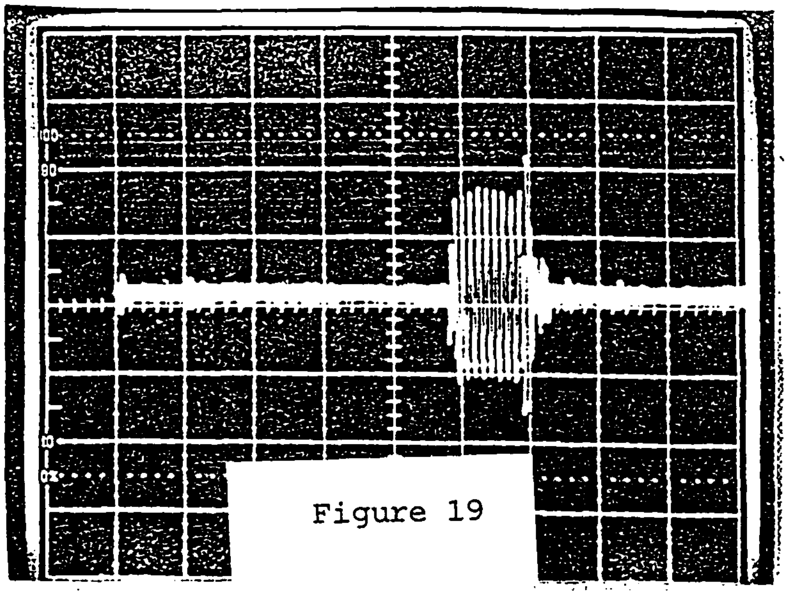


Figure 19

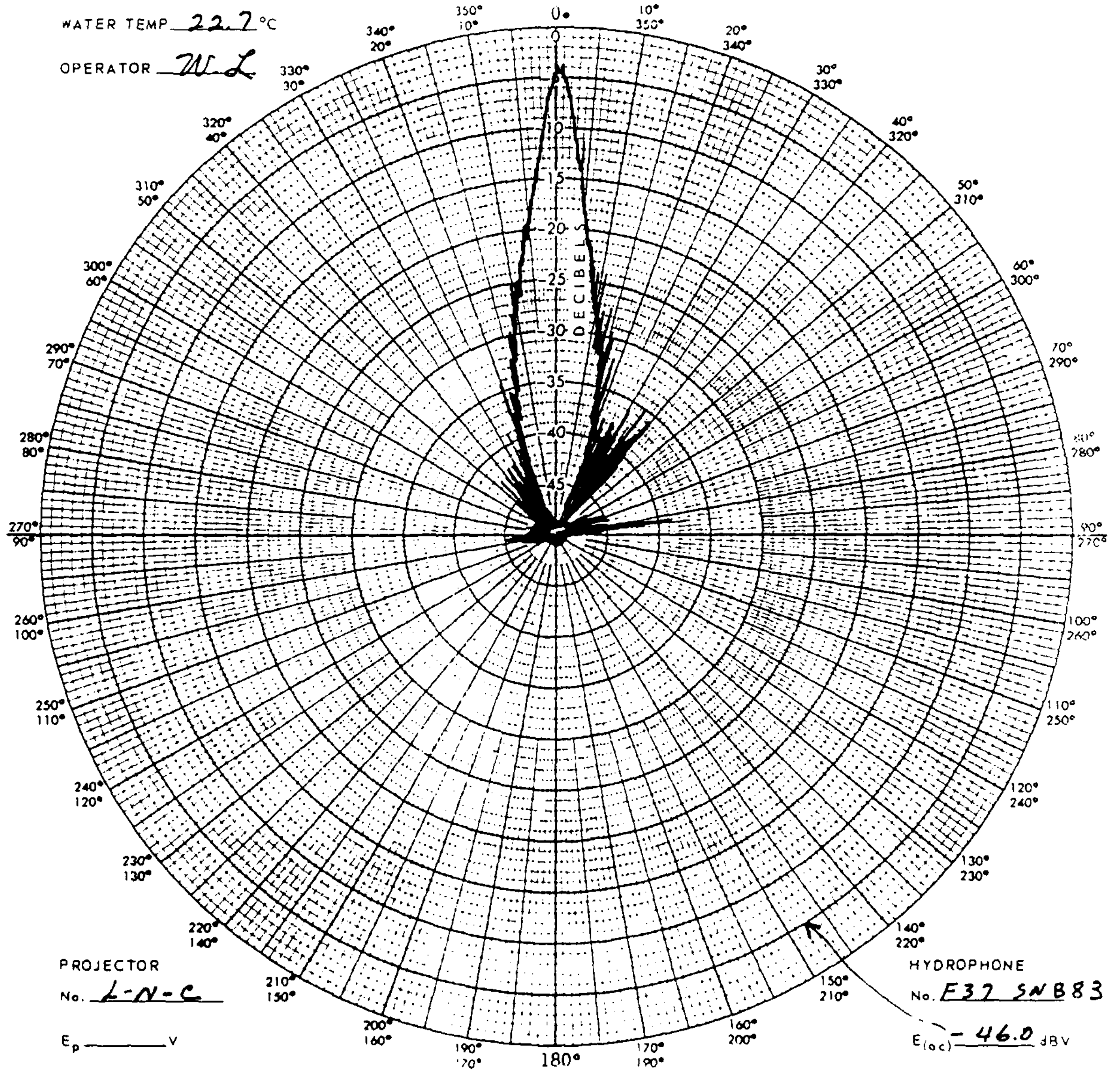
4.1 kHz pulse generated by water itself. Sweep=2ms/div.

APPLIED RESEARCH LABORATORIES
DIRECTIVITY PATTERN
TRANSDUCER No. L-N-C
PATTERN MODE

FREQ 6 kHz
R 89'
d 11'
WATER TEMP 22.7 °C
OPERATOR W.L.

DATE MAY 28 1986

REC ✓ PROJ ___ VERT ___ HORIZ ✓



PROJECTOR
No. L-N-C
E_p ______ V
I_p ______ mA

HYDROPHONE
No. F37 SN B83
$E_{(oc)}$ - 46.0 dBV
REC. SENS. ______

Figure 20

PRF ______ Hz, XMIT PUL ______ GATE LENGTH .4 msec

CABLE TYP

NOTES 1. 6 kHz difference grequency beamwidth measurement

BP w/2KHZ BW

CHAPTER 4

TESTS IN THE GRAND SALINE SALT MINE

Setting Up the Nonlinear Sonar in Salt

At our new work station in the salt mine, we found a nice smooth flat spot in the floor, on which we set up the large metal cylinder that holds the fluid and the NLS transducer,see Figure 6. This wasn't too difficult as all the floors in this mine are sawed with a ten foot undercutter (like a chain saw, only bigger). We fired threaded bolts into the floor with a gun, and with caulking compound on the flange,bolted the metal holder,(called a bathtub by the graduate students), to the floor. We drilled a seven inch deep hole in the salt floor a short distance away, for the receiver of the NLS #2 system. The 1-1/2 inch hole nicely fit the 1-1/8 inch diameter F-50 hydrophone. We used castor oil to couple both the sonar transmitter sound energy into the salt and the hydrophone to the sound in salt. The transducer was placed inside the "bathtub" on four bricks that held the transducer above the floor so that castor oil could flow inside the throat of the line-in-cone transducer. Air holes in the top of the transducer allowed the displaced air to escape. To reduce the amount of castor oil needed, volume displacers of foamed urethane were made to take up the space outside the transducer that would normally be filled with fluid. Even so, a complete drum, about 50 gallons, of castor oil was needed to fill the bathtub. Chunks of salt placed on the urethane kept the volume displacers from floating, shown at the bottom of Figure 6.

24 kHz NLS Signals in Salt

We set up the TAMU NLS #1 system at the R-100 station in the mine. Alongside it, we set up the 24 kHz linear sonar system (EDO Western 4034A),as a receiver for the 24 kHz signal expected to be generated by the salt itself. This is by virtue of the two high intensity, colinear beams of sonar power at 90 and 114 kHz. The reflection from the first tunnel below at about 35 feet is clearly shown in the Figure 21, taken at 1 ms/ division sweep. This is clearly the same signal as seen at 5.5 ms with the LINEAR sonar looking straight down at the same location.

At full power into the ENI amplifier, which is 4 volts p/p input, we saw a reflection from the deeper tunnel below at about 13.9 ms. See Figure 22. This corresponds to 98 feet, taking into account the delay time of the pulse through the EDO receiver, and the castor oil delay in the line-in-cone transducer (an additional 7 inches of travel through the castor oil). The speed of sound in castor oil is 1477 m/s as given by the Handbook of Materials Science, C.T. Lynch,1974. Water is 1496 m/s;they are very close. The EDO receiver delay depends on the pulse width, and has been measured as:

Pulse Width in ms	Delay Time in ms
0.1	0.39
0.3	0.53
0.5	0.69
1.0	1.04

The shortest pulse width is usually used for short range, high-resolution probing; the longest for long range probing.

With a 1 ms pulse width, at maximum power output for the TAMU NLS #1 system, we can see through 200 feet of salt as shown by the signal at 27.5 ms in Figure 23. The longest range signal we observed with this system was with a 2 ms pulse width, and reached 257 feet.

Radar Checks Of Sonar Data

The Foxtrot radar, developed by us for mining safety, was used to check the sonar targets. A block diagram is shown of Foxtrot in Figure 24. A photograph of the radar system is shown in Figure 25. Radar parameters of Foxtrot are shown in Figure 26. Salt has a known relative electric permittivity of 5.9, and so the true electromagnetic wave speed of the radar in salt is given by c/ e/e, where c is the speed of light, and the unit under the radical is 5.9 for salt. The radar speed,or half the true speed, is then 203 feet per microsecond (or 0.2 ft/ns). The Foxtrot operates at 4300 MHz and the wavelength in salt is only 1.1 inches. Thus we have high resolution, but not much range, only to about 150 feet.

A comparison of 24 kHz sonar linear data looking into the floor at Station 100 A, with the radar data from the same place is given below.

Signal	#1	#2	#3
Sonar	39.7 ft.	50.4 ft.	97.2 ft.
Radar	37.8	57	96

Figure 27 shows an oscilloscope photograph of the 96 ft reflector below the salt floor. It arrives at 480 nanoseconds, corresponding to a range of 96 feet in salt, see arrow. The scope sweep is 100 ns/div.

36 kHz Linear Sonar In Salt

Using the TAMU NLS #2 system in the linear mode, we have the capability of operating one of the two line-in-cone transducer sets, as both a receiver and a transmitter. This is the 36 kHz set of piezoelectric crystals. Thus, using the ENI power amplifier with 3.3 volts p/p going in, and with a 0.5 ms pulse width we saw a large (saturated) 14 ms signal from the tunnel below at 97 feet. We looked for a multiple and saw a signal at 27 ms, showing that we could get transmissions through almost 200 feet of rock salt.

Grand Saline Tests, TAMU NLS #2

The first time we tried this system in the salt mine, we started with the linear sonar at 36 kHz. Using a pulse width of 0.5 ms., we observed the first reflection from the deep tunnel below (96 ft.) as well as a multiple of this reflection. The two arrows of Figure 28 show the first reflection and the first multiple of this signal on a photograph of the oscilloscope taken at 5 ms./div., and with 2.75 volts p/p into the ENI amplifier. Note that these signals are saturating the amplifier, i.e.have flat tops. Also note that the second multiple does not show up on the data. Possibly this is because of the narrow beam we have. We should get more transmission than a couple of hundred feet.

In setting up the big transducer in the "bathtub" holding the fluid, we had four 2-1/4 inch blocks holding the lip of the cone off the undercutter-sawn floor. This is so

that the castor oil fluid could flow under the lip of the transducer and fill the cone. The top of the cone has air escape holes so that the fluid can displace the air on the inside of the cone. In addition, in reducing the sonar data using this cone, we must take account of the time of travel for the signal getting through the castor oil. The distance from any transducer to the urethane reflector forming the cone, and then down to the cone face, is always the same for each transducer, so that the signals all arrive in phase. This is 18 inches. Thus there is a delay of 18 plus 2.25 inches or 0.52 meters of travel though the castor oil for the outgoing signal. An equal delay for the signal coming back yields 1.02 meters, at a sound speed of 1477 m/s for castor oil true velocity. Added to this, one must take into account the receiver delay (because we always measure received signals at their peak, not at their beginning because this is too difficult to determine in the presence of noise). This additional delay is usually at least half the pulse width.

Trying to drive the salt nonlinearly, we found a problem in the system. Although each of th ENI 1140LA amplifiers would drive the 36 kHz linear sonar all right, the two amplifiers connected to the T-R box going to the transducer would not both operate at the same time. We spent some time before finding a short circuit in the T-R box --in one of the transformers-- and had to send it back to the manufacturer.

Salt Mine Testing --6 kHz Nonlinear Sonar Tests

On November of 1989, we returned to the Texas salt mine with the TAMU NLS #2 system. First we tried the transducer at 36 kHz in a linear mode with System B receiver. This is to give the castor oil time to degas from the air trapped in the oil when filling the holder. The high intensity sound beam of the 36 kHz waves tend to coalesce the air trapped in the castor oil, and it rises to the top. This increases the signal strength, as the entrapped air attenuates the sound as air is compressible.

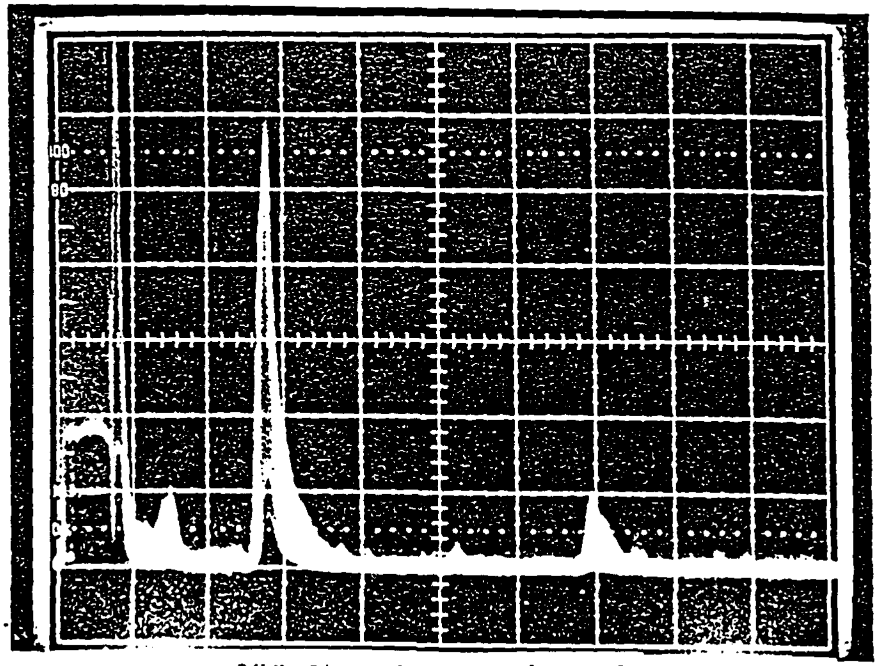
The usual 14 ms signal from the tunnel below at 96 feet showed even without the use of the ENI amplifier. With 0.6 volts p/p into the ENI, we saw the first and second multiple or we obtained about 286 feet of sonar penetration. With 6 volts into the ENI, we saw signals to 59 ms or about <u>430 feet of salt penetration</u>.

Next we tried the nonlinear beam at 6 kHz. Since the period of a 6 kHz wave is 167 microseconds, we chose 12 cycles of this wave to generate in the salt, and thus we needed to irradiate the salt with two pulsed sound beams of 2 ms in length. We used receiver System E. With 4 volts p/p into the ENI of 55 dB gain, we were then feeding almost 800 volts into the transducers. Squaring this and dividing by 50 ohms, assumed to be the real part of the complex impedance of the transducer, we then had 12.9 kW of power in each beam. The result was that the overload red light of the Geopulse receiver lit up immediately. We checked the output of the Butterworth filter and found signals of 37 volts. So it was no surprise the receiver was overloaded. A reduction of ENI input to 0.2 volts yielded only 31 watts of transducer power. This is not enough to drive the salt nonlinearly. So we could not see any 6 kHz signal.

With no sonar transmitters on, we looked at the noise of the receiving system E, with 58 dB gain on the Geopulse. The red light was still on, and we saw 20 volts p/p of noise as shown in Figure 29. We know that these are sound waves in the salt itself, as they are not picked up in the air (hydrophone in the air), nor are they received electromagnetically. The source of this noise is all the transformers in the mine used to convert the original high voltage coming into the mine to a voltage of 1150 volts for motors and other mining equipment such as belt drives. All the transformers sit on the salt and when the 60 Hertz is applied, it drives the iron to magnetic saturation TWICE each cycle, according to the hystersis loop of iron. Thus the iron core of the transformer expands and contracts twice each 60 times a second, and the 120 pulses are detected by our hydrophone. It is difficult to filter out as the pulses are rich in harmonics. Of course, the harmonics decrease with increasing frequency, but are such that they allow us to do 24 kHz nonlinear tests but are too large at 6 kHz for us to detect the nonlinear signal.

In addition, large signals are picked up by the receiving system at t=0, and we need to develop some circuitry that would generate the inverse of this pulse and cancel it at t=0. This should not be too hard to do, and would help the overload situation with the receiver. It would be similar to the seismic systems that cancel out the so-called "high-line" signals of 60 Hz that are picked up by the geophone cables magnetically.

A spectrum analyzer plot of the acoustic noise energy in salt as a function of frequency is shown in Figure 30. Note the large peak of noise in salt at 6 kHz, see arrow.



24kHz Linear Sonar Signal From 2
Tunnels Below

Figure 21

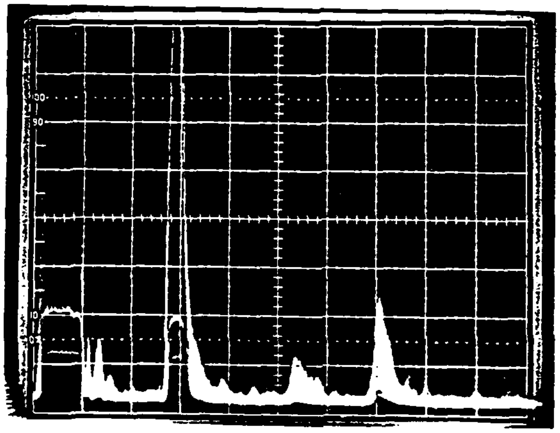


FIGURE 22

24 kHz nonlinear signal
at 13.9 ms

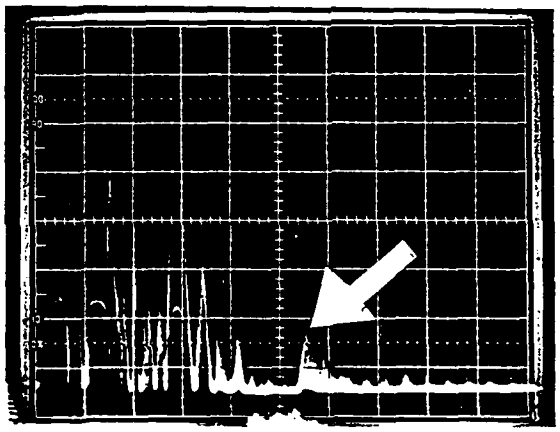


Figure 23

24 kHz nonlinear signal
at 27.5 ms

Foxtrot I Radar System

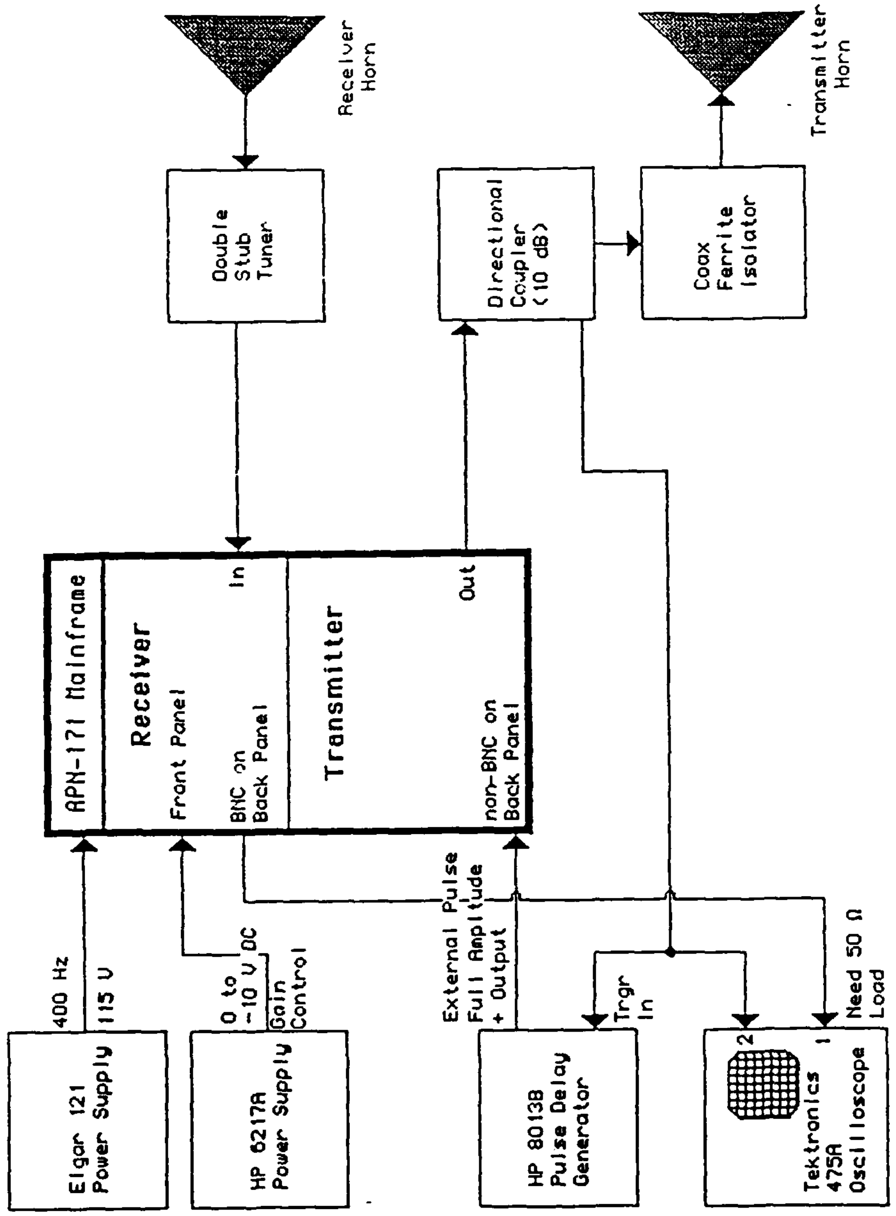


Figure 24

Foxtrot radar block diagram

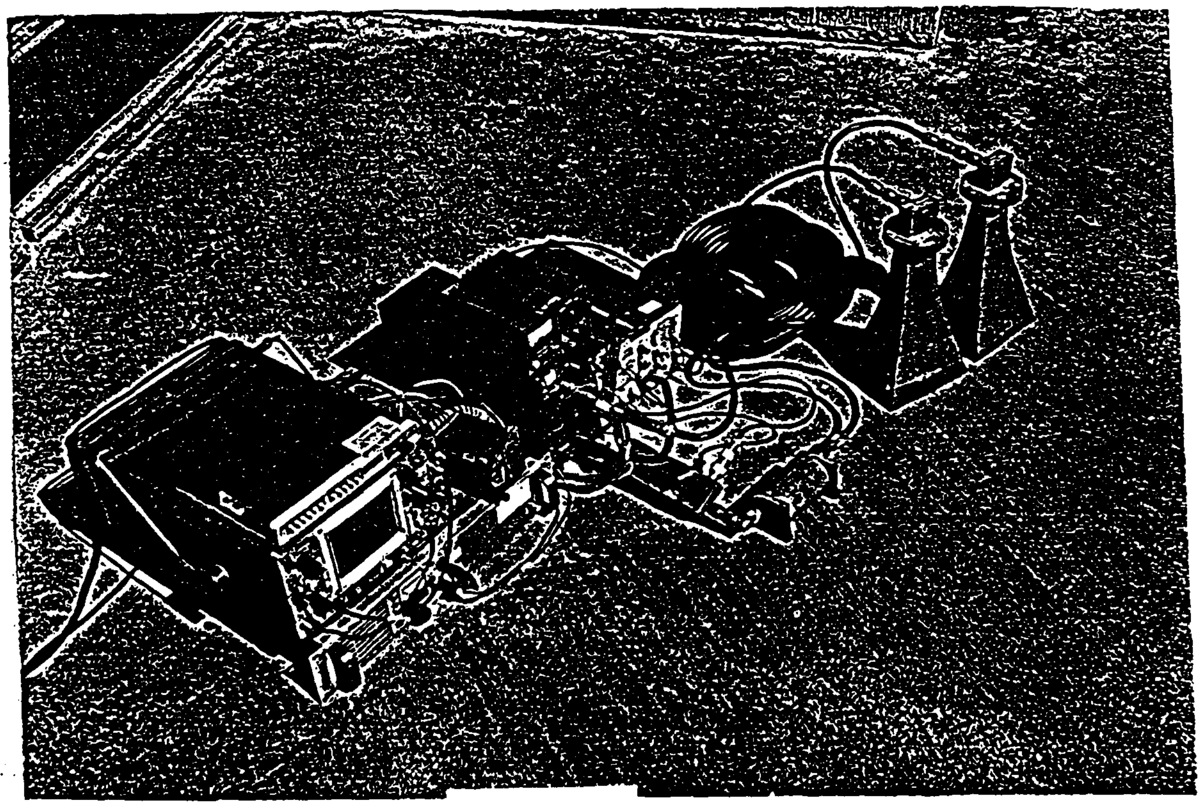


Figure 25

Foxtrot radar photograph

FOXTROT I RADAR PARAMETERS

APN-171

Transmitter Frequency	4300 MHz
Pulse Width (0-1000ft)	35 ± 10 ns
Pulse Width (1000-5000 ft)	130 ± 25 ns
Peak Power (0-1000 ft)	25 to 100 W
Peak Power (100-5000 ft)	100 to 300 W
PRF	10 kHz
Receiver Bandwidth (0-1000 ft)	30 MHz
Receiver Bandwidth (1000-5000ft)	10 MHz
Antenna Pattern (3dB)	± 35° (both E and H) *
Antenna Gain	13 dB Δ
Altitude Accuracy	± 5ft
Power Required	115, $^{+4}_{-8}$ V, 400 ± 20 Hz
	100 volt-amperes
	28 v d.c. 1W. (40 mA)
	5 v a.c. 0.25 W.

λ air = 6.977 cm, 2.747 in

λ salt = 2.87 cm, 1.131 in assumes $\varepsilon'/\varepsilon_o = 5.9$

λ granite = 2.92 cm, 1.15 in assumes $\varepsilon'/\varepsilon_o = 5.7$ as for EE-1 granite

* Calculated E beam = 40°
H beam = 26.7°

Δ Calculated gain = 13.86 dB

Figure 26

Foxtrot radar parameters

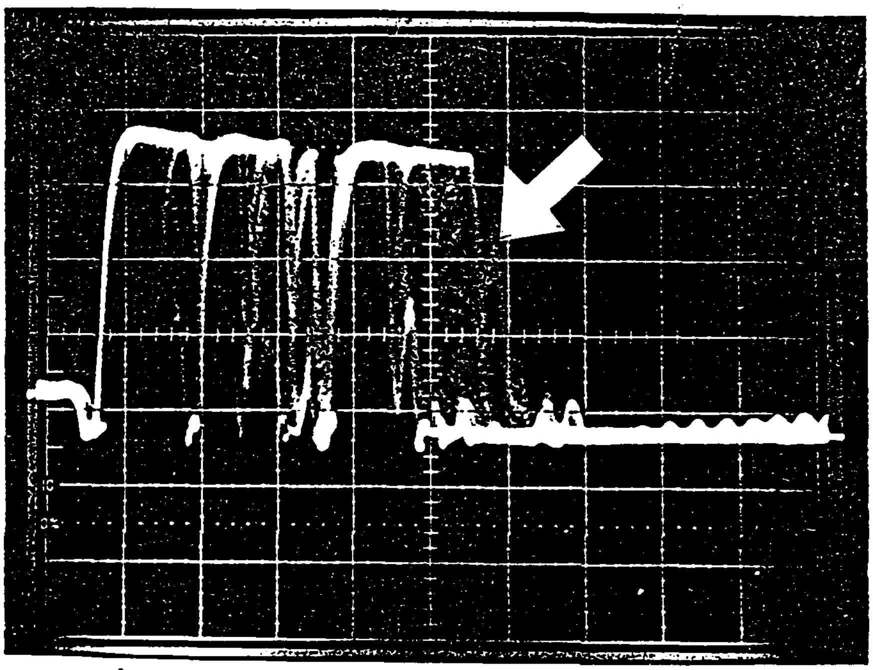
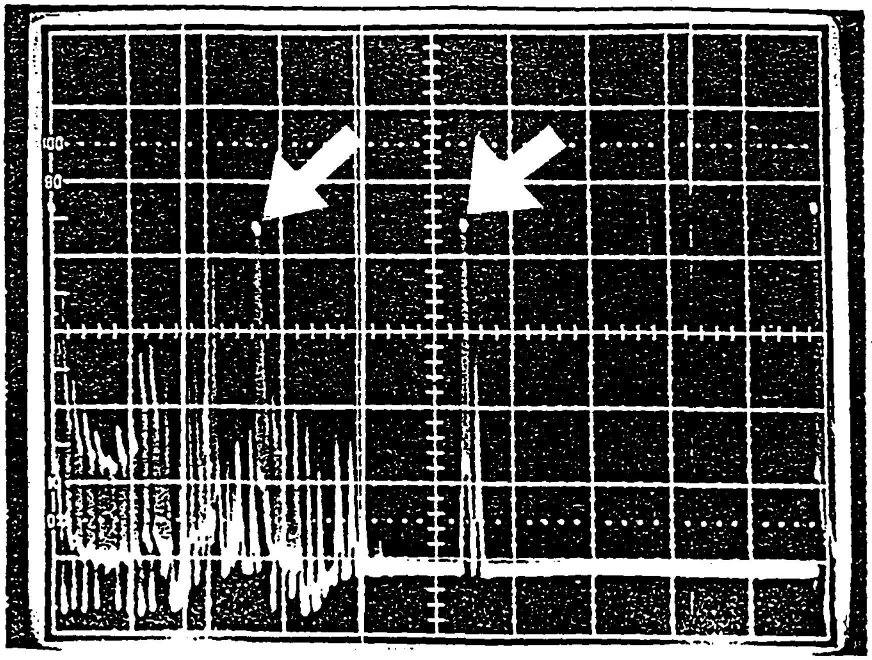


Figure 27

Radar data showing signal 96 feet
through salt



36 mKz Linear sonar, salt probing
showing first multiple

Figure 28

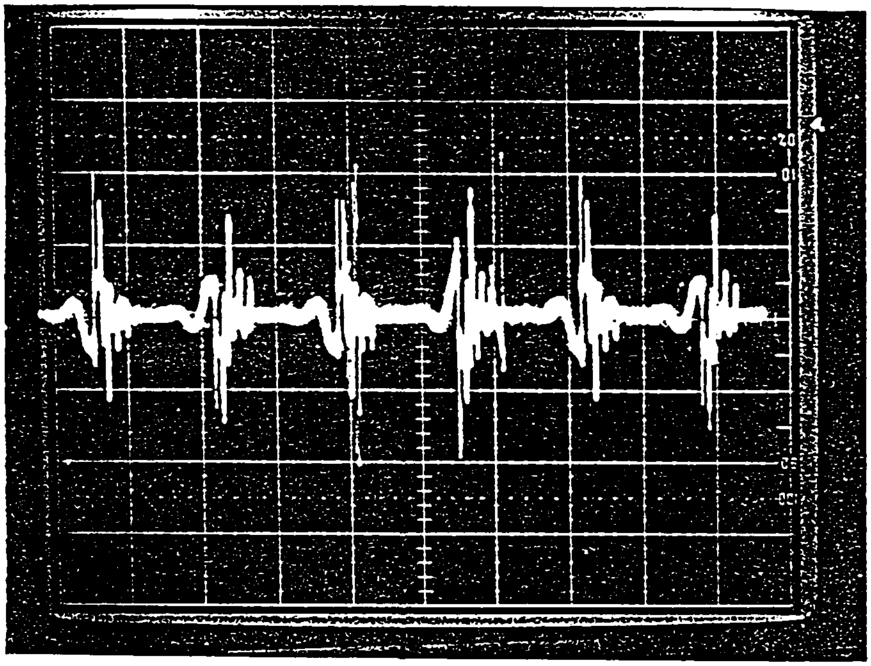


Figure 29

120 Hz noise in salt from
mine power transformers

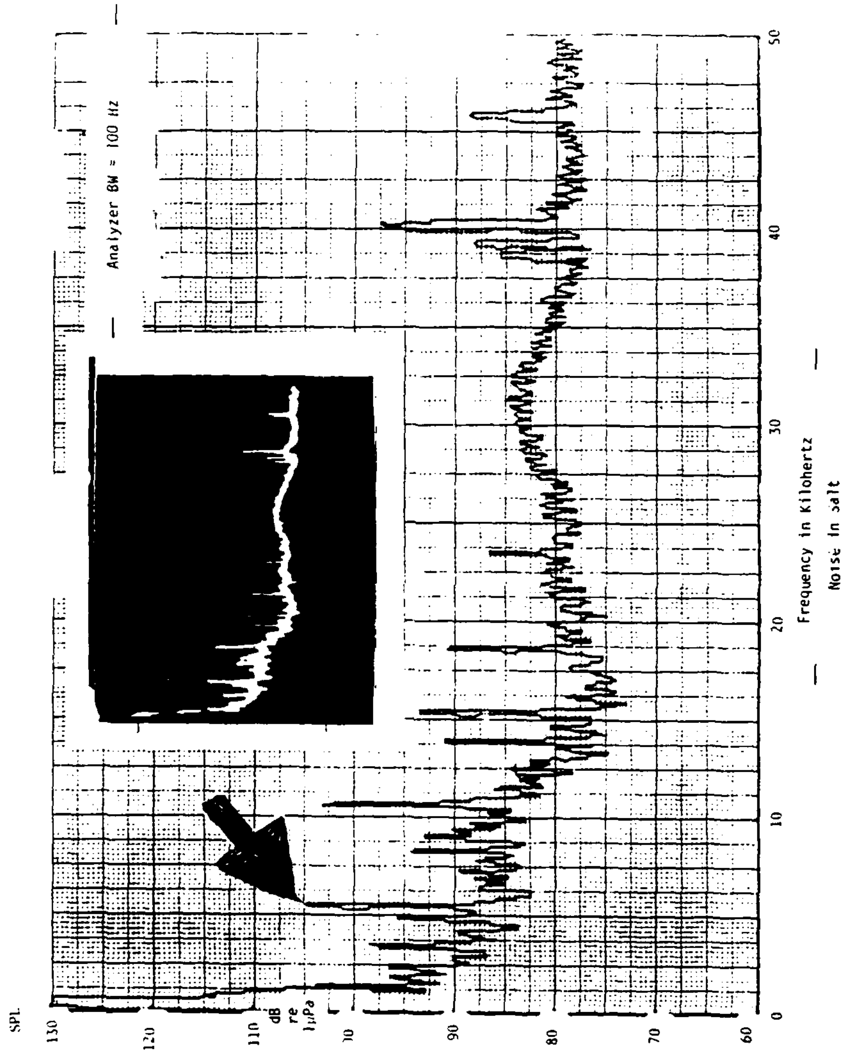


Figure 30

Acoustic noise in salt

CHAPTER 5

CONCLUSIONS

This project did not accomplish all that was planned in the beginning for three reasons. First the P.I was on faculty development leave when the project was supposed to start. Second, the solid rock tests of the equipment was performed in a salt mine in East Texas. Here corrosion of the electronics gave us a lot of repair problems because the salt dust gets into everything. Third, the P.I. had a heart attack in mid-project that slowed him down. In spite of these set-backs we have completed the design and construction of two nonlinear sonar systems, TAMU NLS #1 and #2. The first operates at a difference frequency of 24 kHz and uses a receiver that is a complete EDO Western 4034A sonar system in itself. We simply shut off the transmitter, and used it as a receiver only. With this nonlinear system we were able to probe a maximum distance of 257 feet (78 m) straight down in a salt mine.

System #2 has a difference frequency of 6 kHz, for the reason of obtaining more range in the rock than System #1. The lower primary frequencies will be less attenuated in salt and thus travel further, thereby giving us a better beam forming at the difference frequency. We were unable to detect clearly, difference frequency signals at 6 kHz in the salt mine for reasons that are still unclear. First we found we had an unusually high noise level at 6 kHz.(see Figure 30,p.41). Second, we found we had 20 volts p/p of 120 Hz signals picked up by the hydrophone (acting as a receiver for the System #2). These signals are sound waves (pulses) in the salt that are caused by the mine transformers. Each transformer has its iron core saturated (which thereby expands) twice for each of the 60 cycles of primary power. Thus each transformer acts as a transducer sending out signals at 120 Hz (see Figure 29, p.40). Third, we had very large signals at the hydrophone due to the primaries at t=0, that saturated the Geopulse receiver, which in turn could not recover fast enough to see the difference frequency signals. By turning down the power of the primaries, we did not get this, but we then couldn't drive the salt hard enough to generate the difference frequency we needed. Fourth, when in actual use in the mine, we had some difficulties with the 10 kHz Butterworth filters. These however, had passed our lab tests before. The project ended before we had time to untangle these problems.

On a brighter side, the 36 kHz linear sonar built into the System #2 by virtue of a T-R box in the system operated fine. We got transmisson though almost 200 feet of salt rock looking straight down. We really expected more range from this unit, but the reason could be that we simply did not have any acoustic impedance change down below to give us a reflected signal. Usually we depend on seeing a multiple, sometimes as many as three or four or five, of the salt-air interface of the tunnel 97 feet below to give us a good probing range estimate. Although the roof below is blasted, and hence not particularly flat, the floor into which the transducer is coupled, is flat by virtue of being sawed by an undercutter. At 36 kHz, we did see the first multiple, but we did not see any futher ones. However this could be due to the fact that we have a very narrow beamwidth for this transducer (only 2.7 degrees as shown in Figure 15).

CHAPTER 6.

ACKNOWLEDGEMENTS

It is with great pleasure that the author acknowledges the fine help given him by three outstanding graduate students who worked on this project. They are, Luis Lopez-Aguiar, John Mims and Michael Thornton. In addition, we are grateful for the privilege of doing subsurface testing in the salt mine of Morton Salt Co. of Chicago, located in Grand Saline, Texas. We thank Mr. Robert Hardiman, mine manager, Mr. Don Yarborough, and all his underground workers that helped us do the research in the mine. Lastly, we are grateful for the advice and help given by our consultant on this project, Dr. Thomas Muir, of the Applied Research Laboratory of the University of Texas in Austin.

APPENDIX A

THE MODEL 34 AND DIGITIZING PROGRAMS

MODEL 34 CAPABILITIES

The Model 34 can handle up to 16,000 samples at a sampling rate of 40,000 samples per second. It can sample up to eight channels and has the capability of turning on and off external equipment. The Model 34 card is turned on by the first attempt to sample a signal voltage. This means that, unless the card has already been turned on, the first sample is meaningless.

The sampling is controlled by a machine language program that is written by a program called CODEWRITER. The machine language sampling routine is stored just below DOS in the memory, and the data are stored in binary just below the machine language program. HIMEM is set for the bottom of the data field. Twelve bits are used to describe each data point so each point uses two bytes of memory. The relation between the high bytes and the low bytes varies according to sampling rate. Fast sampling (i.e. faster than 27,430 samples/second) requires an iterative code rather than a more compact code with loops. The faster routines therefore store the data in alternating blocks of 256 high bytes and 256 low bytes. The matching low byte is always 256 bytes higher in memory than its high byte mate. Programs that sample slower than 27,430 Hz store the data in alternate high and low bytes with the low byte stored just above the high byte. See Section 3 of the Model 34 manual for more details.

We put the Model 34 in Slot #7 (as recommended in the manual) and connected input Channel #0 to a BNC connector which was installed on the computer's side panel. Any signal (voltage) we wish to digitize and store is fed in here.

PROGRAM SONAR.DATA.TAKE

The CODEWRITER programs list an AppleSoft program that extracts the digital data from its binary form in memory and list it as text onto the screen. For our example, this AppleSoft program is called SONAR.DATA.TAKE. The data are placed just below the machine language program in the computer's RAM (random access memory). To insure that neither the machine language program nor the data are written over by AppleSoft programs, the first step of SONAR.DATA.TAKE is to set HIMEM just

below the data field (line 1). The next line of SONAR.DATA.TAKE defines the function that converts the binary sample values to text values (line 9) Next the program calls the machine language program that begins and controls the sampling (line 60). With the sample values placed in the computer's RAM, SONAR.DATA.TAKE uses the defined function to list the data onto the screen. The last line of SONAR.DATA.TAKE, a POKE command, turns off the Model 34 card (if the AppleSoft program were written by CODEWRITER 3 only).

In order to avoid running CODEWRITER 3 to place the machine language program into memory every time we want to digitize a signal, we saved the machine language program onto the disk as SONAR.SIM. Before the CALL statement in the AppleSoft program (line 60), we added a BLOAD instruction (line 50) that loads SONAR.SIM into its original memory location. Likewise we added a BSAVE command (line 65) to store the digital data values in a binary disk file, called SONAR.DATA, just after the CALL statement:

```
1 HIMEM: 35584
9 DEF FN VOLTS (N) = PEEK (36351 + N - INT ((1024 - N) / 256) * 256) * 256 + PEEK (36607
     + N - INT (36607 + N - INT ((1024 - N) / 256) * 256)
50 PRINT CHR$ (4) ; "BLOAD SONAR.SIM"
55 POKE 49268, 1 : REM SLOW DOWN MODEL 34 TO 1 MHZ
60 CALL 37632
62 POKE 49268, 0 : REM SPEED UP MODEL 34 TO 3.5 MHZ
65 PRINT CHR$ (4) ; "BSAVE SONAR.DATA, A35584, L2048"
70 FOR N = 1 TO 1024
80 PRINT FN VOLTS(N) / 409.6, N
90 NEXT N
100 POKE 50945, 0 : REM TURN OFF MODEL 34 CARD
```

PROGRAM SONAR.DATA.TRIGGERED

To trigger the Model 34, a sync signal is attached to the Apple //e game-port, and a few lines are added to the program SONAR.DATA.TAKE. The new lines write a short machine language program that calls the program SONAR.SIM when the voltage at the game-port reaches 0.17 V on a negative slope. The CALL statement (line 60) therefore calls the new machine language program (CALL 768) rather than the one written by CODEWRITER 3 (CALL 37632). We named this modified program SONAR.DATA.TRIGGERED:

```
1 HIMEM: 35584
9 DEF FN VOLTS (N) = PEEK (36351 + N - INT ((1024 - N) / 256) * 256) * 256 + PEEK (36607
     + N - INT (36607 + N - INT ((1024 - N) / 256) * 256)
10 FOR N = 0 TO 12 : READ X
20 POKE 768 + N, X : NEXT X
30 DATA  44, 97, 192, 16, 251, 44, 97, 192, 48, 251, 76, 0, 147
50 PRINT CHR$ (4) ; "BLOAD SONAR.SIM"
55 POKE 49268, 1 : REM SLOW DOWN MODEL 34 TO 1 MHZ
60 CALL 768
62 POKE 49268, 0: REM SPEED UP MODEL 34 TO 3.5 MHZ
65 PRINT CHR$ (4) ; "BSAVE SONAR.DATA, A35584, L2048"
70 FOR N = 1 TO 1024
80 PRINT FN VOLTS(N) / 409.6, N
90 NEXT N
100 POKE 50945, 0 : REM TURN OFF MODEL 34 CARD
```

Note: To trigger the sampling on a positive slope rather than a negative slope, exchange the positions of the numbers 16 and 48 in the DATA statement on line 30.

PROGRAM BI.TEXT.SONAR

The programs SONAR.DATA.TAKE and SONAR.DATA.TRIGGERED store the sample values as a binary data file, which we called SONAR.DATA. In order to use the FFT program for transforming, plotting, and listing the data points, the binary file on the CODEWRITER 3 disk must be converted to a text file, which we called SONAR.TEXT, located on the FFT disk. Using the function defined by the CODEWRITER 3 program, we wrote a short program, which we called BI.TEXT.SONAR, that transforms SONAR.DATA to SONAR.TEXT.

Program BI.TEXT.SONAR first sets the HIMEM just below the location of the data field so that AppleSoft programs will not write over the data values. Next it defines the function that converts the binary values to text values (line 9). The next three program lines (lines 60, 62, & 64) load the binary data into the computer RAM and open a text file for writing on disk drive 2. The FFT disk therefore needs to be placed in drive 2 and the CODEWRITER disk needs to be in drive 1. The first three values of the text file must contain information needed by the FFT program. For a real time function, the first and third values are the number of data points, and the second value is the base two logarithm of the number of points. These values are entered on line 66. The rest of the text file data are the digital representation of a *complex* function or signal. The FFT program therefore requires that the data points be entered as real and imaginary pairs. The first value is the real value at the sample point, and since we are

using real time functions, the second, imaginary value is zero. Program lines 70, 80, and 90 enter these values into the text file. Finally, the program closes the text-file (line 95):

```
1 HIMEM : 35584
9 DEF FN VOLTS (N) = PEEK (36351 + N - INT ((1024 - N) / 256) * 256) * 256 + PEEK (36607
     + N - INT (36607 + N - INT ((1024 - N) / 256) * 256)
30 C$ = CHR$(4)
60 PRINT C$ ; "BLOAD SONAR.DATA"
62 PRINT C$ ; "OPEN FFT.SONAR.TEXT,D2"
64 PRINT C$ ; "WRITE FFT.SONAR.TEXT"
66 PRINT 1024 : PRINT 10 : PRINT 1024
70 FOR N = 1 TO 1024
80 PRINT FN VOLTS (N) / 409.6 : PRINT 0
90 NEXT N
95 PRINT C$ ; "CLOSE FFT.SONAR.TEXT"
```

PROGRAM FFT.TRIPLE

The program FFT, which was coded by Joe Walston on July 17, 1982, can transform a function between the time and frequency domains and list or plot the function's values in either the time or the frequency domain. In order to print the plots of the function on our ImageWriter II printer, we added BSAVE commands on lines 721 and 756 that save the bit map of the Apple's graphics screen to the disk. We called this modified FFT program FFT.TRIPLE. The binary files of the screen can then be read and printed by the program TRIPLE.DUMP.

In order to transform and plot the data, without printing the plots on the printer, run FFT, which will not save the graphics screen to the disk. Otherwise run FFT.TRIPLE in order to save the time and frequency plots to the disk so they can be printed by TRIPLE.DUMP.

```
4 REM MENU DRIVEN FAST FOURIER TRANSFORM PROGRAM
5 REM CODED BY JOE WALSTON, JULY 17, 1982.
6 REM PLOTS MAY BE PRINTED ON AN EPSON PRINTER EQUIPPED WITH AN ORANGE
     MICRO GRAPPLER CARD.
10 PI = 3.141592654 : ZN = 90 : ZM = ZN + ZN : ZD = ZM / PI : EP = 1E - 20 : NP = 0 : MP = 0 :
     DP = 0 : LP = 0
15 D$ = CHR$ (4) : P$ = CHR$ (34) : E$ = "" : ESC = CHR$ (27) : B$ = CHR$ (7)
20 DIM P (1024, 1) : GOTO 1000
35 PRINT B$; B$; B$; B$; B$
40 X = PEEK ( - 16384) : IF X < 128 THEN 40
45 POKE - 16384, 0 : IF X < > 155 THEN RETURN
50 ONERR GOTO 1000
55 POP : POP : POP : POP : POP : POP : GOTO 1000
```

```
60 HOME : INVERSE : PRINT "DISK I/O RELATED ERROR # " ; PEEK (222) : NORMAL :
    POKE 216, 0 : GOSUB 35 : GOTO 1000
65 HOME : INVERSE : PRINT "REQUEST " ; M$ ; "IS ABORTED" : NORMAL : PRINT : PRINT
    "EITHER THE DATA FILE IS EMPTY, OR " : PRINT "TOO FEW DATA POINTS ARE
    PRESENT, OR" : PRINT "THE DATA IS FROM THE WRONG DOMAIN"
70 GOSUB 35 : GOTO 1000
75 PRINT : IF T > 2 THEN 90
80 PRINT "FOR HARMONIC ORDER = " ; J - 1 ; ", ENTER: " : IF T = 1 THEN INPUT "SINE
    COEFICIENT = " ; P (J, 0) : INPUT "COSINE COEFICIENT = ; P (J, 1) : RETURN
85 INPUT "ABSOLUTE MAGNITUDE = " ; U1 : INPUT "PHASE ANGLE (DEGREES) = " ; U2 :
    U2 = U2 / ZD : P (J, 0) = ABS (U1) * COS (U2) : P (J, 1) = ABS (U1) * SIN (U2) : RETURN
90 PRINT "FOR WAVEFORM SAMPLE # " ; J ; ", ENTER :" ; INPUT "REAL AMPLITUDE = " ;
    P (J, 0) : IF T = 3 THEN P (J, 1) = 0 : RETURN
95 INPUT "IMAGINARY AMPLITUDE = " ; P (J, 1) : RETURN
100 IF NP < = 0 THEN 65
105 T = -1 : GOTO 115
110 T = 1 : IF NP > = 0 THEN 65
115 N3 = ABS (NP) : IF MP < > N3 THEN 65
120 N2 = N3 / 2 : N1 = N3 -1 : J = 1 : FOR I = 1 TO N1 : K = N2 : VTAB 5 : PRINT I
125 IF I < J THEN X = P (J, 0) : P (J, 0) = P (I, 0) : P (I, 0) = X : X = P (J1, 1) : P (J1, 1) = P (I, 1) ; P
    (I, 1) = X
130 IF K < J THEN J = J - 1 : K = K / 2 : GOTO 130
135 J = J + K : NEXT  : L1 = 1 : FOR L = 1 TO OP : L2 = L1 : L1 = L1 + L1 : U1 = 1 : U2 = 0 : W2
    = PI / L2 : W1 = COS (W2) : W2 = T * SIN (W2) : VTAB 7 : PRINT L ; "/" ; OP
140 FOR J = 1 TO L2 : FOR I = J TO N3 STEP L1 : I1 = I + L2 : V1 = P (I1, 0) * U1 - P (I1, 1) * U2
    : V2 = P (I1, 1) * U1 + P (I1, 0) * U2
145 P (I1, 0) = P (I, 0) - V1 : P (I1, 1) = P (I1, 1) - V2 : P (I, 0) = P (I , 0) + V1 : P (I, 1) = P(I, 1) + V2 :
    NEXT
150 V1 = U1 : U1 = U1 * W1 - U2 * W2 : U2 = U2 * W1 + V1 * W2 : NEXT : NEXT
155 IF NP > 0 THEN FOR I = 1 TO N3 : P (I , 0) = P (I, 0) / N3 : P (I, 1) = P (I, 1) / N3 : NEXT
160 NP = - NP : GOTO  1000
170 U1 = P (J, 0) : IF ABS (U1) < EP THEN U1 = 0 : P (J, 0) = 0
175 U2 = P (J, 1) : IF ABS (U2) < EP THEN U2 = 0 : P (J, 1) = 0
177 I = J : IF T < 3 THEN I = J - 1
180 IF T < > 2 THEN 225
185 IF U1 = 0 THEN U1 = ABS (U2) : U2 = ZN * SGN (U2) : GOTO 225
190 IF U2 < > 0 THEN 205
195 W1 = ABS (U1) : W2 = 0 : IF U1 > 0 THEN 220
200 U1 = W1 : U2 = ZM : GOTO 225
205 W1 = SQR (U1 * U1 + U2 * U2) : W2 = ZD * ATN (U2 / U1) : IF U1 > 0 THEN 220
210 IF U2 > 0 THEN W2 = ZM + W2 : GOTO 220
215 W2 = W2 = ZM
220 U1 = W1 : U2 = W2
225 PRINT I ; TAB ( 7) ; U1 ; TAB ( 25) ; U2 : RETURN
230 IF NP = 0 OR MP < 1 THEN 65
231 EP = 0 : FOR J = 1 TO MP : U1 = ABS (P (J, 0)) : IF U1 > EP THEN EP = U1
232 U2 = ABS (P (J, 1)) : IF U2 > EP THEN EP = U2
233 NEXT EP = EP * 1E - 7
235 N2 = 0 : IF NP > 0 THEN T = 3 : N3 = 16 : GOTO 245
240 PRINT "DO YOU WISH TO SEE" : PRINT : PRINT "  1) SINE/COSINE COEFFICIENTS,
    OR" : PRINT "  2) MAGNITUDE AND PHASE?" : PRINT : INPUT "(1 OR 2)? " : T : IF T < 1
    OR T > 2 THEN HOME : GOTO 240
245 VTAB (23) : PRINT "PRESS <ESC> FOR MAIN MENU." : PRINT "PRESS ANY OTHER
    KEY TO CONTINUE." :  POKE 35,21 : HOME : IF LP THEN PRINT D$ ; "PR#1" : PRINT I$
    ; "5L" : PRINT : PRINT : PRINT E$ : PRINT
```

```
250 HOME : IF T = 3 THEN PRINT TAB ( 12) ; "WAVEFORM SAMPLES" : PRINT "POINT" ;
    TAB (12) ; "REAL" ; TAB ( 27) ; "IMAGINARY" : PRINT : GOTO 270
255 PRINT TAB ( 10) ; "HARMONIC FREQUENCIES" : PRINT "ORDER" ; : IF T = 1 THEN
    PRINT TAB ( 12) ; "SINE" ; TAB ( 29) ; "COSINE" : GOTO 265
260 PRINT TAB ( 10) ; "MAGNITUDE" ; TAB ( 25) ; "PHASE (DEGREES)"
265 VTAB (4) : IF T < 3 THEN : PRINT "THE DC COMPONENT IS ZEROTH ORDER." : PRINT
    "THE FUNDEMENTAL IS FIRST ORDER." : PRINT : N3 = 12
270 POKE 34, 3 : IF LP THEN N1 = N2 + 1 : N2 = MP : GOTO 280
275 N1 = N2 + 1 : N2 = N1 + N3 :IF N2 > MP THEN N2 = MP
280 FOR J = N1 TO N2 : GOSUB 170 : NEXT : GOSUB 40 : IF N2 < MP THEN HOME : N3 = 16
    : GOTO 275
285 GOTO 1000
290 IF MP < 2 OR NP > 0 THEN 65
295 PRINT : PRINT "SUPPLYING COMPLEX CONJUGATE FREQUENCIES." : MP = - NP : L2
    = MP : L1 = MP /2
300 FOR J = 2 TO L1 : P (L2, 0) = P (J, 0) : P (L2, 1) = - P (J, 1) : L2 = L2 -1 : NEXT GOTO 1000
350 IF NP = 0 OR MP = 0 THEN 360
355 FLASH : PRINT "ERASE DATA NOW IN FILE?" : NORMAL : PRINT : INPUT "(Y/N)? " ; M$
    : LEFT$ (M$, 1) < > "Y" THEN 1010
360 HOME : E$ = "" : NP = 0 : MP = 0 : OP = 0 : PRINT "WHAT KIND OF DATA WILL BE
    ENTERED?": PRINT
365 PRINT "HARMONIC FREQUENCY COMPONENTS IN" : PRINT "      1) SINE/COSINE
    COEFICIENT FORM, OR" : PRINT "          2) REAL AND IMAGINARY AMPLITUDES."
370 PRINT : PRINT "INSTANTANEOUS WAVEFORM SAMPLES IN" : PRINT : PRINT       3)
    REAL AMPLITUDE FORM, OR" : PRINT REAL AND IMAGINARY AMPLITUDES
375 VTAB (12) : CALL - 958 : INPUT "SELECTION (1-4) ? " ; T : IF T < 1 OR T > 4 THEN 375
380 HOME : PRINT "ARRAY    HIGHEST     WAVEFORM" : PRINT "GROUP    HARMONIC
    SAMPLES" : PRINT : X = 4 : FOR J = 2 TO 9 : P (J, 0) = X : PRINT "   " : J ; TAB ( 13) ; X / 2 ;
    TAB ( 26) ; X : X = X + X : NEXT
385 VTAB (13) : CALL - 958 : INPUT "ENTER ARRAY GROUP (2-9): " ; OP ; IF OP < 2 OR OP
    > 9 THEN 385
390 NP = P (OP, 0) : N2 = NP : N3 = NP : IF T < 3 THEN N3 = 1 + NP /2 : NP = - NP
400 IF T = 2 THEN PRINT "        HARMONIC FREQUENCIES IN TERMS OF" : PRINT
    MAGNITUDE AND PHASE VALUES. : GOTO 415
405 IF T = 3 THEN PRINT "        SEQUENTIAL SAMPLES OF THE REAL" : PRINT "
    MAGNITUDE OF THE WAVEFORM.". : GOTO 415
410 PRINT "     SEQUENTIAL SAMPLES OF THE COMPLEX : PRINT "
    MAGNITUDES OF THE WAVEFORM."
415 PRINT : PRINT "     A REQUIRED TOTAL OF : N3 : "POINTS."
420 VTAB (10) : CALL - 958 : INPUT "IS THIS CORRECT (Y/N) ? " ; M$ : IF LEFT$ (M$, 1) < >
    "Y" THEN 1010
425 PRINT : PRINT "INITIALIZING ARRAYS." : FOR J = 1 TO N2 : P (J, 0) = 0 : P (J, 1) = 0 :
    NEXT
430 HOME : J =1 : IF T < 3 THEN PRINT "ZERO ORDER IS DC COMPONENT." : PRINT
    "FIRST ORDER IS FUNDAMENTAL FREQUENCY."
435 GOSUB 75 : MP = J : PRINT : PRINT "PRESS <ESC> FOR MAIN MENU. : PRINT
    "PRESS ANY OTHER KEY TO CONTINUE." : GOSUB 40 : IF J < N3 THEN J = J + 1 :
    GOTO 435
440 IF T < 3 AND MP > 1 THEN 295
445 GOTO 1000
450 IF NP = 0 OR MP < 1 THEN 65
455 IF NP < 0 THEN 485
460 T = 4 : PRINT "EDIT WAVEFORM SAMPLE POINTS 1-" ; NP ; "." : PRINT : PRINT
    "(ENTER POINT < 1 TO RETURN TO MENU.)" : PRINT : PRINT "POINT" ; TAB ( 12) ;
    "REAL" ; TAB ( 27) ;" IMAGINARY" : POKE 34, 6
```

```
465 HOME : INPUT "ENTER POINT TO BE EDITED: " ; J : IF J > NP THEN 465
470 IF J < 1 THEN X = FRE (X) : GOTO 1000
475 HOME : GOSUB 170 : PRINT : X = PEEK (37) : INPUT "CHANGE THIS ITEM (Y/N) ? " ; M$
    ; IF LEFT$ (M$, 1) < > "Y" THEN 465
480 VTAB (X) : CALL - 958 : GOSUB 75 : MP = MP + (J - MP) * (J > MP) : GOTO 465
485 N3 = ABS (NP) - 1 : PRINT EDIT FREQUENCIES OF ORDERS 0-" ; N3 : PRINT : PRINT
    "WILL DATA BE ENTERED IN" : PRINT : PRINT "     1)          SINE/COSINE
    COEFFICIENT FORM , OR" : PRINT "          2) MAGNITUDE AND PASE FORM?"
490 VTAB (8) : CALL - 958 : INPUT "SELECTION (1,2) ? " ; T : IF T < 1 OR T > 2 THEN 490
495 VTAB (3) : CALL - 958 : PRINT "THE DC COMPONENT IS ZEROTH ORDER." : PRINT
    "THE FUNDEMENTAL IS FIRST ORDER." : PRINT "ENTER ORDER < 0 TO RETURN TO
    MENU."
500 PRINT : PRINT "ORDER" ; : IF T = 1 THEN PRINT TAB ( 12) ; "SINE" ; TAB ( 29) ;
    "COSINE" : GOTO 510
505 PRINT TAB ( 10) ; "MAGNITUDE" ; TAB ( 25) ; "PHASE (DEGREES)"
510 POKE 34, 8
515 HOME : INPUT "ENTER ORDER TO BE EDITED: " ; J : IF J > N3 THEN 515
520 IF J < 1 THEN X = FRE (X) : GOTO 1000
525 HOME : J = J + 1 : GOSUB 170 : PRINT : X = PEEK (37) : INPUT "CHANGE THIS ITEM
    (Y/N) ? " ; M$ ; IF LEFT$ (M$, 1) < > "Y" THEN 515
530 VTAB (X) : CALL - 958 : GOSUB 75 : MP = MP + (J - MP) * (J > MP) : GOTO 515
600 PRINT "THE DATA WILL BE READ FROM DISK." : NORMAL : T = 0
605 IF NP = 0 OR MP < 1 THEN 65
610 FLASH : PRINT "THE DATA WILLBE WRITTEN TO DISK." : NORMAL : T = 0
615 VTAB (3) : CALL - 958 : PRINT "ENTER THE NAME OF THE FILE." : INPUT "FILE NAME
    = " ; E$ : PRINT PRINT "ARE YOU SATISFIED WITH THE NAME" : PRINT P$ ; E$ ; P$ :
    INPUT "(Y, N, OR MENU) ? " ; M$ : M$ = LEFT$ (M$, 1) : IF M$ = "M" THEN 1000
620 IF M$ < > "Y" THEN 615
625 E$ = "FFT." + E$ : PRINT D$ ; "OPEN" ; E$ : IF T THEN 640
630 PRINT D$ ; "DELETE" ; E$ : PRINT D$ ; "OPEN" ; E$ :PRINT D$ ; "WRITE" ; E$ :
635 PRINT MP : PRINT OP : PRINT NP : FOR J = 1 TO MP : PRINT P (J, 0) : PRINT P (J, 1) :
    NEXT : GOTO 650
640 PRINT D$ ; "READ" ; E$ : INPUT MP, OP, NP : IF MP > 0 THEN FOR J = 1 TO MP : INPUT
    P (J, 0), P (J, 1) : NEXT
645 I = ABS (NP) : IF MP < I THEN FOR J = MP + 1 TO I : P (J, 0) = 0 : P (J, 1) = 0 : NEXT
650 PRINT D$ ; "CLOSE" : PRINT : PRINT MP ; " COMPLEX POINTS WERE
    TRANSFERRED." : GOSUB 35 : GOTO 1000
700 IF NP = 0 OR MP < 2 THEN 65
705 IF NP > 0 THEN 730
710 N3 = 1 - NP / 2 : T = 0 : PRINT "SETTING UP TO PLOT FREQUENCY SPECTRUM." : FOR
    J = 2 TO N3 : U1 = P (J, 0) : U2 = P (J, 1) : U2 = U2 * U2 + U1 * U1 : T = T + (U2 - T) * (U2 >
    T) : NEXT
715 W1 = INT (0.1 - 512 / NP) : W2 = 191 / SQR (T) : HGR2 : HCOLOR = 3
720 I = 0 : FOR J = 2 TO N3 : U1 = P (J, 0) : U2 = P (J, 1) : U1 = SQR (U1 * U1 + U2 * U2)) * W2 :
    HPLOT I, 191 - INT ((U1) TO I, 191 : I = I + W1 : NEXT
721 PRINT D$; "BSAVE PICT.SPECTRUM, A$2000, L$2000" : GOTO 760
730 PRINT "SETTING UP TO PLOT WAVEFORM" : W2 = 0 : W1 = 0 : FOR J = 1 TO NP : T = P
    (J,0) : IF T > W1 THEN W1 = T
735 IF T < W2 THEN W2 = T
740 T = P (J1, 1) : IF T > W1 THEN W1 =T
745 IF T < W2 THEN W2 = T
750 NEXT : U1 = 191 / (W1 -W2) : T = ABS (U1 * W1) : HGR2 : HCOLOR = 3 : HPLOT 0,T TO
    279, T
755 N3 = 279 / NP : N2 = 0 : FOR J =1 TO NP : V1 = (W1 - P (J, 0)) * U1 : HPLOT N2, V1 :
    HPLOT N2, V2 : N2 = N2 + N3 : NEXT
```

```
756 PRINT D$; "BSAVE PICT.WAVEFORM, A$2000, L$2000"
760 GOSUB 35 : IF LP = 0 THEN 1000
765 TEXT : HOME : PRINT PRINTING PLOT." : PRINT D$ "PR#1" : PRNT ESC$ ; CHR$ (12) :
      PRNT I$ "GDR2"
770 PRINT ESC$ ; CHR (2) : PRINT I$ "25L" : PRINT : PRINT : PRINT E$ : PRINT
1000 POKE 216, 0 : PRINT D$ "PR#0"
1010 TEXT : HOME : PRINT "FAST FOURIER TRANSFORM PROGRAM MENU" : PRINT : ON
      SGN (NP) + 2 GOTO 1015, 1020, 1025
1015 PRINT "THE DATA ARE IN FREQUENCY DOMAIN." : GOTO 1030
1020 PRINT "NO DATA LIST IS PRESENT." : GOTO 1030
1025 PRINT "THE DATA ARE IN TIME DOMAIN."
1030 PRINT : PRINT : "THE PRINT IS " ; IF LP THEN INVERSE : PRINT "ON" ; : NORMAL
      PRINT "." : GOTO 1040
1035 PRINT "OFF"
1040 PRINT : PRINT "[A] READ THE DISK CATALOG." : PRINT "[B] READ A DATA FILE
      FROM DISK." : IF NP < > 0 AND MP > 0 THEN PRINT "[C] WRITE THE DATA FILE TO
      DISK."
1045 PRINT "[D] TOGGLE THE PRINTER." : PRINT "[E] INITIALIZE NEW FILE AND ENTER
      DATA." : IF NP = 0 THEN 1070
1050 PRINT "[F] EDIT THE DATA FILE." : IF MP > 0 THEN PRINT "[G] LIST THE DATA FILE."
1052 IF MP > 1 THEN PRINT "[H] PLOT THE DATA FILE."
1055 IF MP < > ABS (NP) THEN 1067
1060 IF NP > 0 THEN PRINT "[I] MOVE FROM TIME TO FREQUENCY DOMAIN." : GOTO
      1070
1065 IF NP < 0 THEN PRINT "[J] MOVE FROM FREQUENCY TO TIME DOMAIN."
1067 IF MP > 1 AND NP< 0 THENPRINT "[K] FILL COMPLEX CONJUGATE
      FREQUENCIES."
1070 PRINT "[Z] QUIT THE PROGRAM." : PRINT : X = PEEK (37) + 1
1075 INPUT "SELECT A MENU ITEM BY LETTER (A-Z): " ; M$ : T = ASC ( LEFT$ (M$ + " ", 1))
      : IF T = 90 THEN HOME : END
1080 IF T < 65 OR T > 75 THEN VTAB (X) : CALL - 958 : GOTO 1075
1085 IF T < 68 THEN ONERR GOTO 60
1090 HOME : ON T - 64 GOTO 1100, 600, 605, 1095, 350, 450, 230, 700, 100, 110, 290
1095 LP = NOT LP : GOTO 1010
1100 PRINT D$ "CATALOG" : GOSUB 35 : GOTO 1000
```

APPENDIX B

PROGRAM TARGET SEARCH

INTRODUCTION

Luis Lopez and I developed Program Target Search to pick out sonar reflections from a digitized sonar trace. The program scans the trace and records all points that have an amplitude (voltage) greater than a certain user defined percentage of the maximum amplitude value which is chosen by the user. A single target is identified by the set of points that lie between the point that crosses the detection level on a positive slope and the point that crosses the detection level on a negative slope. The user then has the choice of listing the "targets" on the screen or on the printer, drawing a plot of the data, listing the digital data points on the screen or on the printer, calculating multiples for individual targets, or re-entering the necessary input (such as time between the start of the signal and the signal's peak value, scan level, etc.).

FILE TDATA

A Lawson Labs Mode 34 A/D converter digitizes sonar signals and stores binary values of signal voltages in the computer's RAM (random access memory). These binary values can either be stored on the disk as a binary data file or be converted to real values and stored as a text file. The binary file uses less memory, but Program TARGET SEARCH and Program FFT both need the data stored as text files. The text file for Program TARGET SEARCH needs to have the name "TDATA".

For data stored in a binary file, Program BI.TDATA.SONAR converts a binary data file into the text file "TDATA" by using the conversion function that Program CODEWRITER 3 defined. For a more direct approach, Program MULTISTACK, which is described in Appendix C, takes multiple sampling traces, stacks them, and can write the stacked data into the text file TDATA.

PROGRAM INPUTS

Before Program TARGET SEARCH can detect potential reflections, the user needs to enter several values. This section describes the prompts and input values.

Enter the # of samples:

The total number of sample points in the file TDATA determines the maximum value that can be entered here. Entering a value that is greater than the number of points in TDATA will result in an "end of data" error that will interrupt the program. Any positive number of points fewer than the total, however, can be used. The program then enters the given number of sample values into an array.

Enter sampling frequency (samples/second):

Enter the sampling frequency used in Program CODEWRITER 3 or preferably enter the measured sampling frequency in Hz. The sampling frequencies for CODEWRITER 3 sampling rates of 10 kHz, 20 kHz, and 40 kHz have been measured to actually be 9.625 kHz, 20.4 kHz, and 40.8 kHz, respectively. For each of these sampling frequencies, a sampling disk has been made with the measured sampling rates already written into the respective TARGET SEARCH programs. The sampling frequency is used to convert each sample point number into a time value.

Enter pulsewidth/2 in ms (zero to define the middle of signal):

This prompt can be misleading for asymmetric signals. The user should actually enter his best approximation of the time between the leading edge of the largest signal and the position of the signal's maximum amplitude as seen on an oscilloscope (using units of milliseconds). If the user wants the program to list the time of each reflection's maximum amplitude instead of the leading edge of each reflection, he should enter the value of "0". The program uses the value to locate the leading edge of each signal, which is used for distance estimates to each reflector and for calculations of the location of multiples. It is unfortunate that this value must be a user input. The program would be much stronger if we could find an algorithm that would calculate this value for asymmetric as well as symmetric signals when the user enters the actual pulse width.

Enter the rock sound speed (m/s):

Enter a measured or estimated sound speed for the propagation medium. The sound speed is used to convert time values of data points to distance values.

Enter time between true zero and the start of sampling (ms):

When using a delay between the actual transmission initiation and the start of sampling the amount of the delay should be entered in milliseconds. The program adds

this value to the time values in order to account for the delayed trigger. If sampling begins at the beginning of transmission, enter zero.

Enter the number of initial samples that are to be ignored:

Originally this input was added to the program because we thought that sampling would always be triggered at the start of transmission. Since the front of the signal has a large amplitude direct feed and reverberation from the transmitter, this input would allow the program to eliminate these points so that they would not be recorded as reflections. When the delayed triggering system was developed, this input was not eliminated because the initial sample point which turns on the Model 34 A/D converter is usually worthless. The user can therefore enter "1", and eliminate the effects of the first, bad sample point. If the card was already on when sampling commenced, then the first point would be valid, and the user can enter zero.

Enter the noise level as a % of the maximum amplitude:

Before this prompt, the program searches the data and lists the maximum and minimum amplitude values. At this point, the user needs to use the oscilloscope to decide at what amplitude level the signals will be above the noise. If the chosen value is too high, then some reflections will not be recorded; if the value is too low, then some noise peaks might be recorded as reflections. The correct level will vary depending on signal amplitudes and noise levels. The program picks a signal by recording the points where amplitudes cross this detection level on an up-slope and on a down-slope. Next, all of the points between these crossing points are scanned in order to pick the value and sample number of the maximum amplitude for the set of points. These steps are repeated until the end of the data array. The program cannot detect more than fifty reflections without causing a syntax error.

THE MENUS

After the program has picked out the reflections, it lists a menu. This section provides a brief explanation of each menu option.

[A] List Targets

Selecting this option will list all of the recorded reflections by "target number", initial arrival time of each signal in milliseconds, distance to the reflector in meters, and the reflection's amplitude relative to the largest recorded amplitude.

[B] Print Targets

This option will list the same information as option [A], except the output will be written on the printer rather than the terminal screen.

[C] List Data

Choosing this option will list every data point beginning with a sample number chosen by the user. The data are listed by sample number, time in milliseconds, and actual amplitude.

[D] Print Data

This option is the same as option [C], except the output is sent to the printer rather than the terminal screen.

[E] Plot Data

Selecting this option will draw an HGR (high resolution) plot of the data scaled to fill the entire HGR screen. After the user hits any key in order to return to the main menu, the drawing is saved to the disk in the binary file PIC.TARGET so that it can later be printed using Program TRIPLE.DUMP.

[F] Calculation of multiples

This option calculates the locations of a chosen reflection's multiples. When the user chooses this option, the computer lists the same table of recorded targets that is presented by choosing option [A] above. The user then chooses a reflection for which he wishes to have multiple locations calculated. After choosing a target, the program calculates the correct position of the signal's multiples and presents a new menu to the user:

[A] Plot multiples of the selected target

Selecting this option will draw the same plot of the data as option [E] above, except that under the plot, short lines locate the correct

position of the maximum amplitude for the selected target and its calculated multiples.

[B] List multiples of the selected target

Choosing this option will show a table of the location of the selected target and its calculated multiple locations in both milliseconds and meters. The selected signal location is listed under multiple number zero.

[C] Print the multiple list

This option will send the list that is presented under multiple calculation option [B] to the printer.

[D] Calculate another multiple

This option allows the user to calculate multiples for a different reflection without returning to the main menu. Choosing this option will again list the table of recorded targets and prompt the user to chose one target for the multiple calculation.

[E] Exit to main menu

Selecting this option returns the user to the main menu.

[G] Reenter Variables

With this option the user can change the values for the "pulsewidth/2", the rock sound speed, the delay between initial transmission and the start of sampling, the number of data point that are to be ignored by the program, and the scan level. Note that for the number of ignored points, the program replaces the original values with zeros, so that re-entering a value smaller than the previous value will not allow the user to see previously hidden points. In order to see points that have been previously ignored, the user must re-enter the entire data array by running the program again.

[Q] Quit

Choosing "Quit" leaves the program and returns the user to DOS 3.3.

OTHER

Line 50 of Program TARGET SEARCH sets LOMEM at 16384. We found this line necessary so that the data array would not be stored in the memory reserved for the HGR graphics screen. Before we added this line, plotting the data would erase part of the data array. Memory limitations has also limited the length of the program. After adding a few more lines to the program, we found that certain options, such as multiple calculations would erase the last few lines of the program so that choosing options [C] or [D] would result in a syntax error because program lines were missing.

Program TARGET SEARCH can now handle at least 1024 sample points. This is enough data to represent 25.6 ms at a sampling rate of 40 kHz, 51.2 ms at a sampling rate of 20 kHz, and 76.8 ms at a sampling rate of 10 kHz. Luis Lopez and I have made three digital sampling and processing disks——one for 40 kHz sampling, one for 20 kHz sampling, and one for 10 kHz sampling. Each disk contains appropriate versions of Program MULTISTACK, Program SONAR.DATA.TRIGGERED, and Program TARGET SEARCH. Using these sampling frequencies and using the delayed triggering system, we should have few problems digitizing sonar traces.

Program TARGET SEARCH would be greatly improved if we could find an algorithm that would determine the distance between the leading edge of a reflection and the point of maximum amplitude for an asymmetric signal when the user enters the pulse width. Since the user sets the pulse width, he should know what it should be, but having the user try to pick out the time from the signal's front end to its peak amplitude from an oscilloscope will cause errors when we try to apply this program to noisy environments where the signal's leading edge is buried in the noise.

VARIABLES IN TARGET SEARCH

Files:

- TDATA: Text file of data
- PIC.TARGET: Binary file of HGR screen so that plot of data can be printed using Program TRIPLE.DUMP

Character variables:

- D$: CHR$(4) {i.e. <Control D>}——for file commands and DOS 3.3 commands in the program
- E$: Dummy variable used to continue after user hits any key
- C$: Option from main menu
- M$: Option from multiple calculation menu

Arrays:

- AMP: Array of all data points
- T: Array that contains the sample number of the leading edge of each recorded reflection
- VOLT: Array that contains the maximum amplitude of each recorded reflection
- MUL: Array of the sample numbers that represent the location of the multiples for a chosen reflection

Index variables:

I, I3, J, K

User input variables:

- N: Total number of sample points
- DT: Sampling frequency/period (in hertz / seconds)
- PW: Time from leading edge of reflection to the point of peak amplitude (in milliseconds)
- V: Rock sound speed (in meters/second)
- TL: Delay between initial transmission and beginning of sampling (in milliseconds)
- J1: Number of points at the beginning of the trace to ignore
- LEV: Percent of the maximum signal that sets the detection level
- TN: Target number for which to calculate multiples

Variables for plotting:

- YAX: Height of plot in pixels——YAX = 159 for plot of data only
  YAX = 139 for plot of data and multiples
- X: Horizontal location of point on plot
- Y: Vertical location of point on plot
- X1: Horizontal location of multiple

Variables for formatting data for output:

- WK: Number of characters needed to write the sample number
- WM: Number of characters needed to write the time
- MS: Formatted time
- WS: Number of characters needed to write the distance
- SI: Formatted distance
- WR: Number of characters needed to write the relative amplitude
- REL: Formatted relative amplitude
- I4: Number of characters needed to write the multiple number
- T3: Formatted time
- T4: Number of characters needed to write the time
- D3: Formatted distance
- D4: Number of characters needed to write the distance
- R3: Formatted relative amplitude
- R4: Number of characters needed to write the relative amplitude
- VT: Formatted actual amplitude (in volts)
- WA: Number of characters needed to write the acrual amplitude

Other variables:

- MAX: Maximum amplitude of the trace
- IMAX: Sample number that has the maximum amplitude
- MN: Minimum amplitude of the trace
- G: Actual value of the detection level (in volts)
- L: Number of recorded reflections

LIST OF TARGET SEARCH

```
20 D$ = CHR$ (4)
50 LOMEM : 16384
100 HOME
130 INPUT "Enter the # of samples: " ; N : PRINT
140 DIM VOLT(50), T(50), AMP(N), MUL(50)
150 PRINT D$ ; "OPEN TDATA"
155 PRINT D$ ; "READ TDATA"
160 FOR I = 1 TO N
170 INPUT AMP (N)
180 NEXT I
190 PRINT D$ ; "CLOSE TDATA"
195 INPUT "Enter  the sampling frequency (Hz) : " ; DT : DT = 1000 / DT : PRINT
200 PRINT "Enter the pulsewidth/2 in ms (zero "
210 INPUT "to define the middle of the signal): " ; PW
215 PW = PW / DT
230 PRINT : INPUT "Enter the rock sound speed (m/s): " ; V
260 PRINT : PRINT "Enter the time between true zero   'd the" : INPUT "start of sampling
    (ms): " ; TL
270 TL = INT (TL / DT)
290 PRINT
300 PRINT "Enter the number of initial "
310 PRINT "samples that correspond to "
320 PRINT "the width of the transmitted "
330 INPUT "pulse: " ; J1
335 PRINT
360 FOR I = 1 TO J1
365 AMP(I) = 0
370 NEXT I
375 MN = 1000
380 MAX = 0.0
385 FOR I = J1 + 1 TO N
390 IF AMP(I) > MAX THEN MAX = AMP(I) : IMAX = I
392 IF AMP(I) < MN THEN MN = AMP(I)
395 NEXT I
400 PRINT "The maximum amplitude is " ; MAX
405 PRINT "and occurs at the sample number " ; IMAX
407 PRINT : PRINT "The minimum amplitude is " ; MN
410 PRINT
415 PRINT "The noise level should be greater "
416 PRINT "than " ; MN / MAX * 100 ; "%"
420 PRINT " Enter the noise level as a % of the"
425 INPUT "maximum amplitude: " ; LEV
426 PRINT
430 G = MAX * LEV / 100
```

```
440 IF (G < MN) OR (G > MAX) THEN 415
500 I = 1.0 : L = 1.0
510 IF (AMP (I)) < G AND (I < N) THEN I = I +1 : GOTO 510
515 IF (I = N) AND (AMP (I) < = G) THEN 620
520 FIRST = I
530 IF (AMP (I) > = G) AND (I < N) THEN I = I + 1 : GOTO 530
540 LAST = I - 1
545 IF (I = N) AND (AMP (I) > G) THEN LAST = LAST + 1
550 PRINT "FOUND A TARGET!!" : F$ = CHR$(7) : PRINT F$
555 VOLT (L) = 0
560 FOR J = FIRST TO LAST
570 IF AMP (J) > VOLT (L) THEN VOLT (L) = AMP (J) : T(L) = J - PW
590 NEXT J
600 L = L + 1
610 IF I < N THEN 510
620 L = L - 1
800 HOME : PRINT "Choose an option:"
805 PRINT : PRINT TAB (5) ; "[A] List Targets"
810 PRINT : PRINT TAB (5) ; "[B] Print Targets"
815 PRINT : PRINT TAB (5) ; "[C] List Data"
820 PRINT : PRINT TAB (5) ; "[D] Print Data"
825 PRINT : PRINT TAB (5) ; "[E] Plot Data"
830 PRINT : PRINT TAB (5) ; "[F] Calculation of Multiples"
835 PRINT : PRINT TAB (5) ; "[G] Reenter Variables"
900 PRINT : PRINT TAB (5) ; "[Q] Quit"
905 PRINT : PRINT : INPUT "OPTION: " ; C$
910 IF C$ = "A" THEN GOSUB 3000 : GOTO 800
915 IF C$ = "B" THEN PR#1 : GOSUB 3000 : PR#0 : GOTO 800
920 IF C$ = "C" THEN GOSUB 5000 : GOTO 800
925 IF C$ = "D" THEN GOSUB 5000 : GOTO 800
930 IF C$ = "E" THEN GOSUB 2000 : GOTO 800
935 IF C$ = "F" THEN GOSUB 4000 : GOTO 800
940 IF C$ = "G" THEN HOME : GOTO 200
995 IF C$ < > "Q" THEN 800
996 HOME : PRINT "DONE!!! WHEW!!!!" : END
2000 REM  SUBROUTINE THAT PLOTS THE DATA
2005 HOME : HGR : CALL 62450 : HCOLOR = 7
2007 YAX = 159 : IF C$ = "F" THEN YAX = "139"
2008 HCOLOR = 3 : HPLOT 0, YAX TO 279, YAX
2010 FOR I = 1 TO N
2012 Y1 = AMP(I)
2020 X = INT (I * 279 / N) : Y = INT (Y1 * YAX / MAX)
2030 HPLOT X, YAX - Y, TO X, YAX
2040 NEXT I
2044 IF C$ = "F" THEN RETURN
2045 VTAB 24
2050 PRINT TAB (14) ; "Plot o f Data"
2060 PRINT "Hit any key to continue " : GET E$
2062 PRINT D$ ; "BSAVE PIC.TARGET, A$2000, L$2000
2065 TEXT
2066 PRINT D$ ; "BSAVE PIC.TARGET, A$2000, L$2000
2070 RETURN
3000 REM  SUBROUTINE THAT LISTS TARGETS
3005 HOME
3010 PRINT TAB (7) ; "RESULTS OF THE TARGET SEARCH"
```

```
3020 PRINT
3030 PRINT TAB (10) ; "SPEED OF SOUND = " ; V ; " M/S"
3040 PRINT TAB (10) ; RELATIVE NOISE LEVEL = " ; G * 100 / MAX ; " %"
3050 PRINT : PRINT
3051 IF C$ = "A" OR C$ = "F" THEN 3060
3053 PRINT "TARGET" ; SPC ( 15) ; "TIME" ; SPC ( 14) ; "DISTANCE" ; SPC ( 15) ;
    "RELATIVE"
3055 PRINT "NUMBER" ; SPC ( 15) ; "(ms)" ; SPC ( 15) ; "(m)" ; SPC ( 17) ; "AMPLITUDE" :
    PRINT : GOTO 3090
3060 PRINT "TARGET" ; SPC ( 5) ; "TIME" ; SPC ( 4) ; "DISTANCE" ; SPC ( 5) ; "RELATIVE"
3070 PRINT "NUMBER" ; SPC ( 5) ; "(ms)" ; SPC ( 5) ; "(m)" ; SPC ( 7) ; "AMPLITUDE"
3080 PRINT "----------------------------------------"
3090 FOR K = 1 TO L
3100 SI = V * DT * (T (K) + TL) / 2000 : REL = VOLT (K) / MAX : MS = (T (K) + TL) * DT
3105 WK = LEN ( STR$ (K))
3110 MS = INT ( ABS (MS) * 1000 + 0.5) / 1000 * SGN (MS) : WM = LEN ( STR$ ( INT (MS))) + 4
3112 IF MS > = 1 THEM WM = WM + 1 : IF SI > = 1 THEN WS = WS + 1 : IF REL > = 1 THEN WR
    = WR + 1
3115 SI = INT ( ABS (SI) * 1000 + 0.5) / 1000 * SGN (SI) : WS = LEN ( STR$ ( INT (SI))) + 4
3120 REL = INT ( ABS (REL) * 100 + 0.5) / 100 * SGN (REL) : WR = LEN ( STR$ ( INT (REL))) +
    3
3130 IF C$ = "B" THEN 3320
3150 PRINT TAB ( 3) ; SPC ( 2 - WK + 1) ; K ;
3160 PRINT TAB ( 9) ; SPC ( 7 - WM + 1) ; MS ;
3170 PRINT TAB ( 19) ; SPC ( 8 - WS + 1) ; SI ;
3180 PRINT TAB ( 35) ; SPC (4 - WR + 1) ; REL
3190 GOTO 3400
3320 PRINT SPC ( 3 - WK) ; K ;
3330 PRINT SPC ( 23 - WM) ; MS ;
3340 XS% = LEN ( CHR$ (MS - INT (MS))) : PRINT SPC ( 3 - XS%)
3350 PRINT SPC ( 20 - WS) ; SI ;
3360 XS% = LEN ( CHR$ (SI - INT (SI))) : PRINT SPC ( 4 - XS%)
3370 PRINT SPC ( 19 - WR) ; REL
3400 NEXT K
3410 IF C$ = "B" THEN PR#0 : HOME
3415 IF C$ = "F" THEN 3430
3420 PRINT : PRINT : PRINT "Hit any key to continue" ; GET E$
3430 RETURN
4000 REM SUBROUTINE TO CALCULATE MULTIPLES
4010 GOSUB 3000 : PRINT
4020 INPUT "Calculate multiples for target #: " ; TN
4025 I3 = 0
4030 I3 = I3 + 1
4050 MUL (I3) = INT ( (T (TN) + TL) * I3 + PW)
4060 IF MUL (I3) > N + TL THEN I3 = I3 - 1 : GOTO 4100
4065 GOTO 4030
4100 REM MENU FOR CALCULATION OF MULTIPLES
4110 PRINT "Choose an option:"
4120 PRINT : PRINT TAB ( 5) ; "[A] Plot multiples of the selected"
4125 PRINT TAB ( 9) ; "targets"
4130 PRINT : PRINT TAB ( 5) ; "[B] List multiples of the selected"
4125 PRINT TAB ( 9) ; "targets"
4140 PRINT : PRINT TAB ( 5) ; "[C] Print the multiple list"
4150 PRINT : PRINT TAB ( 5) ; "[D] Calculate another multiple"
4160 PRINT : PRINT TAB ( 5) ; "[E] Exit to main menu"
```

```
4145 PRINT : PRINT : INPUT "OPTION: " ; M$
4150 If M$ = "A" THEN GOSUB 4300 : GOTO 4100
4150 If M$ = "B" THEN GOSUB 4500 : GOTO 4100
4150 If M$ = "C" THEN PR#1 : GOSUB 4500 : PR#0 : GOTO 4100
4150 If M$ = "D" THEN 4100
4160 IF M$ < > "E" THEN 4100
4165 IF M$ = "E" THEN RETURN
4300 GOSUB 2000
4310 HCOLOR = 3
4320 FOR I = 1 TO K
4325 X1 = T (TN) + (T (TN) + TL) * (I - 1) + PW
4330 X1 = INT ( X1 * 279) / N)
4340 HPLOT X1, 140 TO X1, 155
4350 NEXT I
4355 HCOLOR = 3 : HPLOT 0, 159 TO 279, 159
4360 VTAB 24 : PRINT "Plot of data & multiples for target # " ; TN
4370 PRINT "Hit any key to continue"
4380 TEXT : RETURN
4500 REM LIST POSSIBLE MULTIPLE LOCATIONS
4505 HOME : I = 0
4507 IF M$ = "B" THEN 4525
4510 PRINT SPC ( 18) ; MULTIPLES FOR TARGET # " ; TN : PRINT
4515 PRINT "MULT" ; SPC ( 15) ; "TIME" ; SPC ( 15) ; "DISTANCE" ; SPC ( 15) ; "RELATIVE"
4520 PRINT " #" ; SPC ( 17) ; "(ms)" ; SPC ( 17) ; "(m)" ; SPC ( 18) ; "AMPLITUDE"
4521 PRINT : GOTO 4554
4525 PRINT TAB ( 8) ; MULTIPLES FOR TARGET # " ; TN : PRINT
4530 PRINT "MULT" ; SPC ( 5) ; "TIME" ; SPC ( 5) ; "DISTANCE" ; SPC ( 5) ; "RELATIVE"
4540 PRINT " #" ; SPC ( 7) ; "(ms)" ; SPC ( 7) ; "(m)" ; SPC ( 8) ; "AMPLITUDE"
4550 PRINT "————————————————————————"
4554 K = 0
4555 K = K + 1 : I = I + 1
4570 T3 = MUL (I) * DT : D3 = T3 * V / 2000 : R3 = AMP (MUL (I) - TL) / AMP (MUL (1) - TL)
4575 T4 = LEN ( STR$ (I)) : T3 = INT ( ABS (T3) * 1000 + 0.5) / 1000 * SGN (T3)
4580 I4 = LEN ( STR$ ( INT (T3)) + 4: IF T3 > = 1 THEN T4 = T4 + 1
4583 IF D3 > = 1 THEN D4 = D4 + 1 : IF R3 > = 1 THEN R4 = R4 + 1
4585 D3 = INT ( ABS (D3) * 1000 + 0.5) / 1000 * SGN (D3) : D4 = LEN ( STR$ ( INT (D3))) + 4
4590 R3 = INT ( ABS (R3) * 100 + 0.5) / 100 * SGN (R3) : D4 = LEN ( STR$ ( INT (R3))) + 3
4595 IF M$ = "C" THEN 4650
4600 PRINT SPC ( 2 - I4 + 1) ; I - 1;
4605 PRINT TAB ( 10) ; SPC ( 7 - T4 + 1) ; T3 ;
4610 PRINT TAB ( 19) ; SPC ( 9 - D4) ; D3 ;
4615 PRINT TAB ( 35) ; SPC (5 - R4) ; R3
4620 GOTO 4680
4650 PRINT SPC ( 2 - I4) ; I - 1;
4655 PRINT ; SPC ( 22 - T4) ; T3 ;
4665 PRINT ; SPC ( 24 - D4) ; D3 ;
4675 PRINT ; SPC (20 - R4) ; R3
4680 IF K < 14 AND I < > I3 THEN 4555
4681 PR#0 : PRINT : PRINT "Hit <ESC> for the menu" : PRINT "Hit any other key to continue"
4682 GET E$
4685 IF I = I3 OR ASC (E$) = 27 THEN RETURN
4687 IF M$ = "C" THEN HOME : PR#1 : GOTO 4554
4690 HOME : GOTO 4525
4705 IF M$ = "C" THEN PR#1 : HOME
4710 PRINT : PRINT : PRINT " Hit any key to continue" : GET E$ : RETURN
```

```
5000 REM SUBROUTINE THAT LISTS THE DATA
5005 HOME : INPUT "Start list with sample # " ; I
5010 HOME : I = I - 1 : IF C$ = "D" THEN PR#1 : GOTO 5012
5011 GOTO 5020
5012 PRINT "SAMPLE" ; SPC ( 15) ; "TIME (ms)" ; SPC ( 15) ; "AMPLITUDE"
5013 PRINT : GOTO 5035
5020 PRINT "SAMPLE" ; SPC ( 5) ; "TIME (ms)" ; SPC ( 5) ; "AMPLITUDE"
5030 "------------------------------------------------"
5035 K = 0
5040 I = I + 1 : K = K + 1
5050 MS = (I + TL) * DT : MS = INT ( ABS (MS) * 1000  + 0.5) / 1000 * SGN (MS)
5060 VT = INT ( ABS (AMP(I)) * 1000  + 0.5) / 1000 * SGN (AMP(I))
5070 WI = LEN ( STR$ (I)) : WM = LEN ( STR$ ( INT (MS))) + 4 : WA = LEN ( STR$ ( INT (VT))) +
     4
5080 PRINT SPC ( 5 - WI) ; I ;
5085 IF C$ = "D" THEN 5104
5090 PRINT TAB ( 8) ; SPC ( 12 - WM) ; MS ;
5100 PRINT TAB ( 24) ; SPC ( 12 - WA) ; VT
5102 GOTO 5110
5104 PRINT SPC ( 3) ; SPC ( 22 - WM) ; MS ;
5106 PRINT SPC ( 4) ; SPC ( 22 - WA) ; VT
5110 IF K < 18 AND I < > N THEN 5040
5115 PR#0
5120 PRINT : PRINT "Hit <ESC> for the menu"
5130 PRINT "Hit any other key to continue" : GET E$
5140 IF I = N OR ACE (E$) = 27 THEN RETURN
5150 IF C$ = "D" THEN HOME : PR#1 : GOTO 5035
5160 HOME : GOTO 5020
```

APPENDIX C

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